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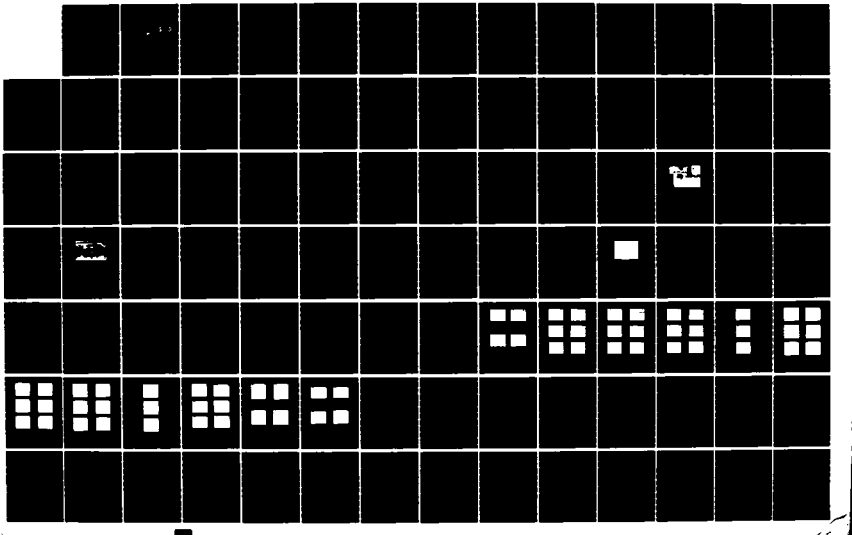

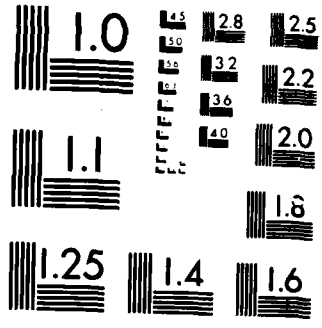

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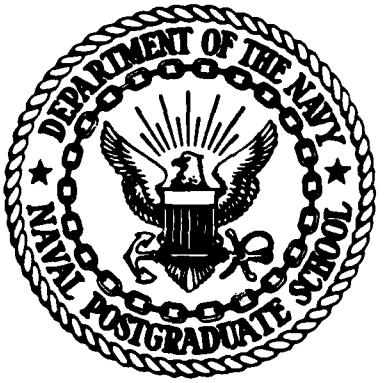

THESIS

ELECTRON INDUCED CONDUCTIVITY OF Al_2O_3
AS PERTAINING TO THERMIONIC INTEGRATED CIRCUITS

by

Peter J. Peterson

December 1985

Thesis Advisor: F. R. Buskirk

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Electron Induced Conductivity of Al_2O_3 as pertaining to Thermionic Integrated Circuits

by

Peter J. Peterson
Lieutenant, United States Navy
B.S., UW River Falls, 1973

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN PHYSICS

from the

NAVAL POSTGRADUATE SCHOOL
December 1985

Author: Peter J. Peterson
Peter J. Peterson

Approved by: Fred R Buskirk
F. R. Buskirk, Thesis Advisor

John R Neighbours
J. R. Neighbours, Second Reader

G. E. Schacher, Chairman,
Department of Physics

J. N. Dyer,
Dean of Science and Engineering

ABSTRACT

Experiments were conducted to measure the electron induced conductivity (EIC) of single crystal sapphire (Al_2O_3) and poly-crystalline alumina (Al_2O_3). The EIC is generated when the samples are bombarded with high energy electrons, utilizing the Naval Postgraduate School's S-band linear accelerator (LINAC). The EIC was measured at dose rates up to 6×10^7 rad (Si)/sec. The EIC for alumina was an order of magnitude smaller than the value for sapphire. The value calculated for alumina was 10^{-4} $(\Omega\text{-cm})^{-1}$ and 10^{-3} $(\Omega\text{-cm})^{-1}$ for sapphire. The response of EIC to a given dose rate did not change as the dose accumulated. Surface flashover problems during electron irradiation were observed and are discussed.

TABLE OF CONTENTS

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I wish to thank my thesis co-advisors, Professor F. R. Buskirk and Professor J. R. Neighbours for their patience, encouragement, insight and willing assistance.

Thanks are also extended to Don Snyder for his expertise and invaluable help at the LINAC control station.

A special gratification to Dr. Dave Lynn and his co-workers at Los Alamos National Laboratory for providing the EIC samples used in the research and for all of their valuble time and assistance.

I. INTRODUCTION

A. OVERVIEW

Today the United States with its sophisticated weaponry, complex electronic components and internetting communication systems is dependent upon the semiconductor integrated circuit. These electronic systems must be able to perform in hostile radiation environments both natural and man-made. Typical radiation sources include natural space environments, interplanetary and planetary environments for space probes, the cosmic ray environments, nuclear reactor environments and the nuclear weapons environment. Unfortunately semiconductor devices in these high radiation environments have shown an increasing susceptibility to failure. Currently a great deal of money, time and manpower is being utilized to find ways to harden these devices. Hardening is the process of making a device less susceptible to radiation damage and signal upset, thereby increasing system reliability. The penalty inherent in manufacturing high density microcircuits is a decrease in the radiation hardness of the integrated circuit. A new device is needed that can be used in a high radiation environment in conjuction with semiconductors. This new device will require medium to low power requirements, minaturization and speed equivalent to a semiconductor. A

device that has demonstrated great potential to meet the above requirements is the thermionic integrated circuit (TIC). The TIC is a new technology being developed by D. Lynn and J. McCormick et al. at Los Alamos National Laboratory [Ref. 1]. Initial tests show TIC devices are orders of magnitude more resistant to total radiation dose than other integrated circuits. Experimentation on the response of these devices to single event upset is required.

The TIC device is a combination of vacuum tube and integrated circuit technology. A typical single TIC device, a triode, is shown in Fig. 1.1 [Ref. 1]. The device is similar to a standard triode in which the cathode emits electrons, the anode collects electrons and the grid prodvides gain by modulating electron flow. The cathode, anode and heater are photolithographically delineated onto either alumina (Al_2O_3) or sapphire (Al_2O_3) substrates.

In any high energy radiation environment, the Al_2O_3 will be exposed to ionizing radiation. Ionizing radiation generates electron-hole pairs inside the Al_2O_3, creating radiation induced conductivity (RIC). RIC is transient conductivity with pulse times in the nanosecond to microsecond range. Only the high energy thermalized electrons contribute to the RIC since low energy electrons are trapped in approximately 10^{-9} to 10^{-10} sec. High energy electrons that pass through TICs deposit their energy by ionization and displacement damage. Displacement damage

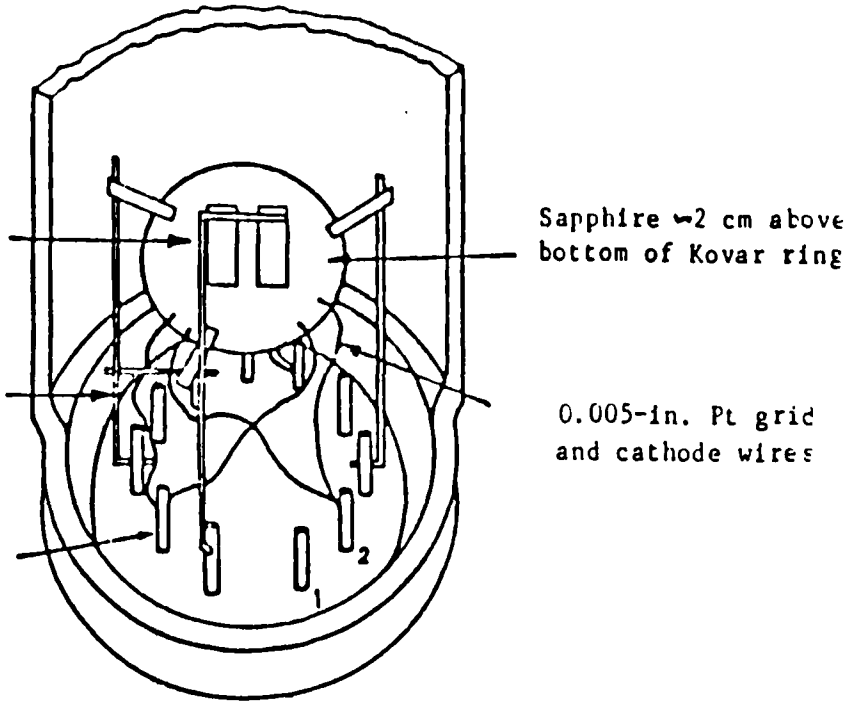


Fig. 1.1. Radiation test triode package configuration. Pin connections during test: 1--not used; 2--cathode through 1 kΩ; 3--shield through 1 kΩ; 4--not used; 5--heater ground; 6--heater +33 V; 7--not used; 8--not used; 9--shield pin floating; 10--grid through 1 kΩ; 11--anode to +60 V.

usually degrades the device by significantly decreasing carrier concentration, carrier lifetime and carrier mobility.

To simulate high intensity ionizing radiation, the Naval Postgraduate School's S-band 100 MeV electron linear accelerator (LINAC) was used. This thesis will discuss the electron induced conductivity (EIC) of high intensity ionizing radiation utilizing 30 and 100 MeV thermalized electrons on single crystal sapphire and poly-crystalline alumina (Al_2O_3).

II. THEORY

A. GENERAL MECHANISMS

1. Energy Levels in Crystalline Insulators

A crystalline insulator is a solid that is built up from its constituent atoms, ions and molecules. These elementary building blocks are packed together in a three-dimensional array called a crystal. Cohesive forces bind the atoms, ions and molecules of the crystal causing the electron energy levels associated with the isolated components to be modified and bunched into bands. The behavior of the energy bands in the crystalline structure determine the fundamental electronic properties of the material. The energy bands may form gaps as shown in Fig. 2.1. The valence band is filled with electrons, the conduction band is unoccupied and they are separated by the energy gap E_g. The size of the energy gap determines the electronic properties of the material. In insulating materials, E_g generally ranges from 5eV to 10eV. The single crystalline sapphire Al_2O_3 and polycrystalline alumina Al_2O_3, used in this thesis have energy gaps of 9eV.

Energy bands in a crystalline insulator are modified by the existence of lattice irregularities. The irregularities give rise to localized energy levels lying between the conduction band and valance band. The

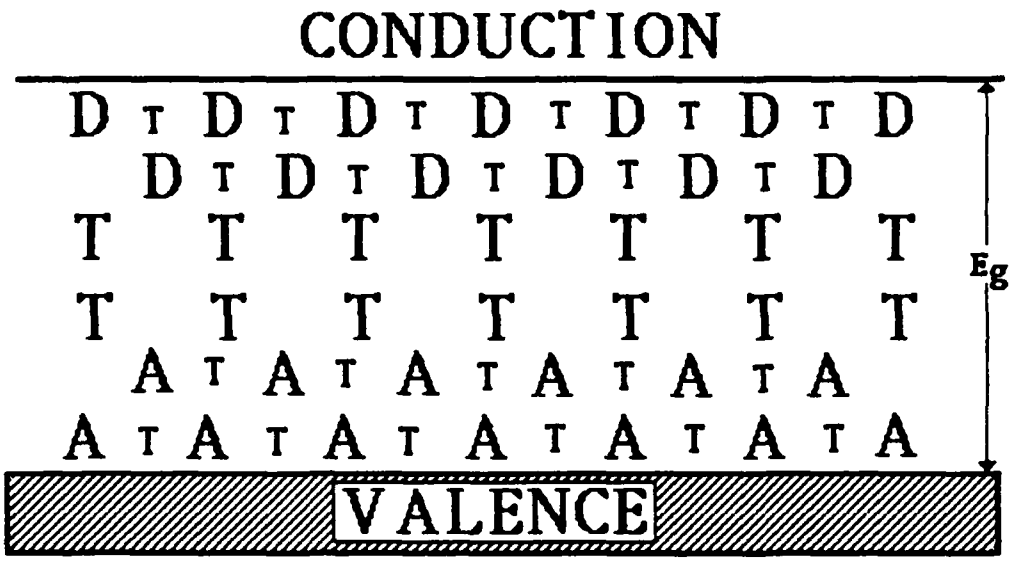


Figure 2.1. Band structure in a crystalline insulator. There is a well defined energy gap Eg between the filled valence band and the empty conduction band. Lattice imperfections and impurities that are localized states act as traps, shown as T in the energy gap. Impurities such as dislocations and point defects give rise to donor levels shown as D and acceptors shown as A.

irr ularities include impurity atoms, stoichiometric exc s, of one or more of the species of atoms, and def mation of the lattice.

In Fig. 2.1, T depicts localized energy states, cal d traps, that capture pseudo-free carriers. Impurities suc as dislocations and point defects give rise to donor lev s, D, and acceptor levels, A.

. Traps

Traps are localized energy states which are capable of pturing charge carriers temporarily. These charge car ers are then thermally emitted into the appropriate ban thereby generating recombination. Levy has shown that uni adiated samples of Al_2O_3 have 3 distinct absorption ban (trapping sites) at energy levels of 6.2eV, 5.45eV, and 4.82eV. After irradiation, the samples show 8 more dis nct trapping sites [Ref. 2]. The presence of traps red es conductivity and response time.

The rate of trapping is given by Eq. (2.1) [Re 3]:

$$D = N[1-f(E)]V\sigma n \qquad (2.1)$$

whe ,

n free electron density in the conduction band

V thermal velocity

σ ≡ trapping cross section

N ≡ trap density

f(E) ≡ Fermi probability function

The product, $V\sigma$ is the volume swept out per unit time by a particle of cross section σ [Ref. 3]. The electron is trapped if the localized state lies within the volume swept out by $V\sigma$. The value of σ may change if a large electric field (on the order of 10^{4}-10^{5} V/cm) is applied. This is called the Poole-Frenkel effect.

The process, in which the initial bombarding electron strikes a lattice atom, is known as the primary collision. The target atom of the lattice is known as the primary knock-on atom. The energy required to displace an atom from its lattice site is called the "threshold energy", E_d. If an atom receives an energy less than E_d, the probability the atom will be displaced is zero. If an atom receives energy greater than E_d, the atom will be displaced. Seitz and Koehler have determined that an E_d of 25eV is required to displace an atom in a solid [Ref. 4]. Arnold and Compton have determined that the minimum threshold energy is 50eV for Al and 90eV for O [Ref. 5].

3. Recombination Centers

Recombination centers are localized impurities or radiation induced lattice deformations located in an otherwise perfect crystalline insulator. These impurities give rise to trapping sites which trap and hold one type of

charge carrier. The carrier remains in the trapping site until the opposite carrier enters the trapping site, causing annihilation. Shallow traps are localized states close to the edges of the valence and conduction bands. Recombination centers are deep energy states in the middle of the energy band gap.

B. ELECTRON INTERACTION WITH MATTER

Electrons interact with matter by elastic scattering with a nucleus, inelastic scattering with atomic electrons and production of secondary knock-on atoms.

As a result of the collision between the high energy electron and the nucleus of the lattice atom, the incident electron imparts some of its energy to the lattice atom. The recoiling atom interacts with surrounding atoms, transferring energy to the rest of the lattice. If the energy of the primary recoiling atom is low, the result is a heating of the crystal lattice. As the energy transferred to the recoil atom increases, a threshold energy E_d is reached. Above E_d the recoil atom is removed from the lattice site to an interstitial site. The movement of the atom from the lattice creates a vacancy. This is referred to as a displacement.

During inelastic Coulomb scattering, high energy electrons interact with the nucleus or atomic electrons of the target atoms. Interaction with the atomic electrons

changes the direction of the bombarding electron causing radiation. Radiation caused by an energy loss of the incident electron is called bremsstrahlung radiation. Bremsstrahlung radiation is given off when an electron slows down as it passes through material.

Secondary knock-on atoms are generated by recoiling atoms with energies greater than 50eV. These atoms interact with the surrounding atoms causing a cascading effect.

Stopping power, as defined by Enge, "is the amount of energy lost by a particle per unit length of path through the stopping material" [Ref. 6]. For electrons, Berger and Seltzer have separated total stopping power into two categories: 1)Collision stopping power and 2)Radiative stopping power. Radiative and collision stopping power both slow electrons.

Collision stopping power is the mechanism which creates ionization energy. Ionization energy is absorbed in the material close to the path of the electron beam. The radiative energy lost due to bremsstrahlung is deposited far from the track of the electron beam. In thin samples, such as the substrates of Al_2O_3, radiative energy loss is not deposited into the material. Collision stopping power causes the energy deposition which is the damage mechanism of importance to this thesis. Therefore, only the collision stopping power will be considered.

The computer simulations of 30 and 100 MeV electron beams incident on a thin cylindrical target of Al_2O_3, were performed using a Cray computer at the Los Alamos National Laboratory. The Cyltran code used is one of the Integrated Tiger Series codes for Coupled Electron /Photon Monte Carlo Transport. Figures 2.2-2.5 illustrate the results of the modeling in graphic form. The angular distribution graphs, Figures 2.2-2.3, show that the overwhelming majority of electrons emerging from the material are at angles between 0 and 18 degrees. The incident electrons shows little deflection as they pass through the material.

The transmitted energy spectrum graphs, Figures 2.4-2.5, show that the majority of electrons leaving the material are at energies between 27-30 or 90-100 MeV. Only a small percentage of the total energy is lost from the beam. Therefore, the Cyltran code confirms that the Al_2O_3 substrate is a thin sample.

1. Collision Stopping Power

The formulas used for collision stopping power in this section are a refinement of Bethe and Heitlers stopping and scattering power theory. The electron mass collison stopping power is given by the formula developed by Rohrlich, Carlson, and Uehling:

$$\frac{1}{\rho}\frac{dE}{dX}_{col} = \frac{2\pi N r_e^2 mc^2 Z}{\beta^2 A}\left[\ln\left(\frac{T}{I}\right)^2 + \ln\left(1+\frac{\tau}{2}\right) + F(\tau) - \delta\right] \qquad (2.2)$$

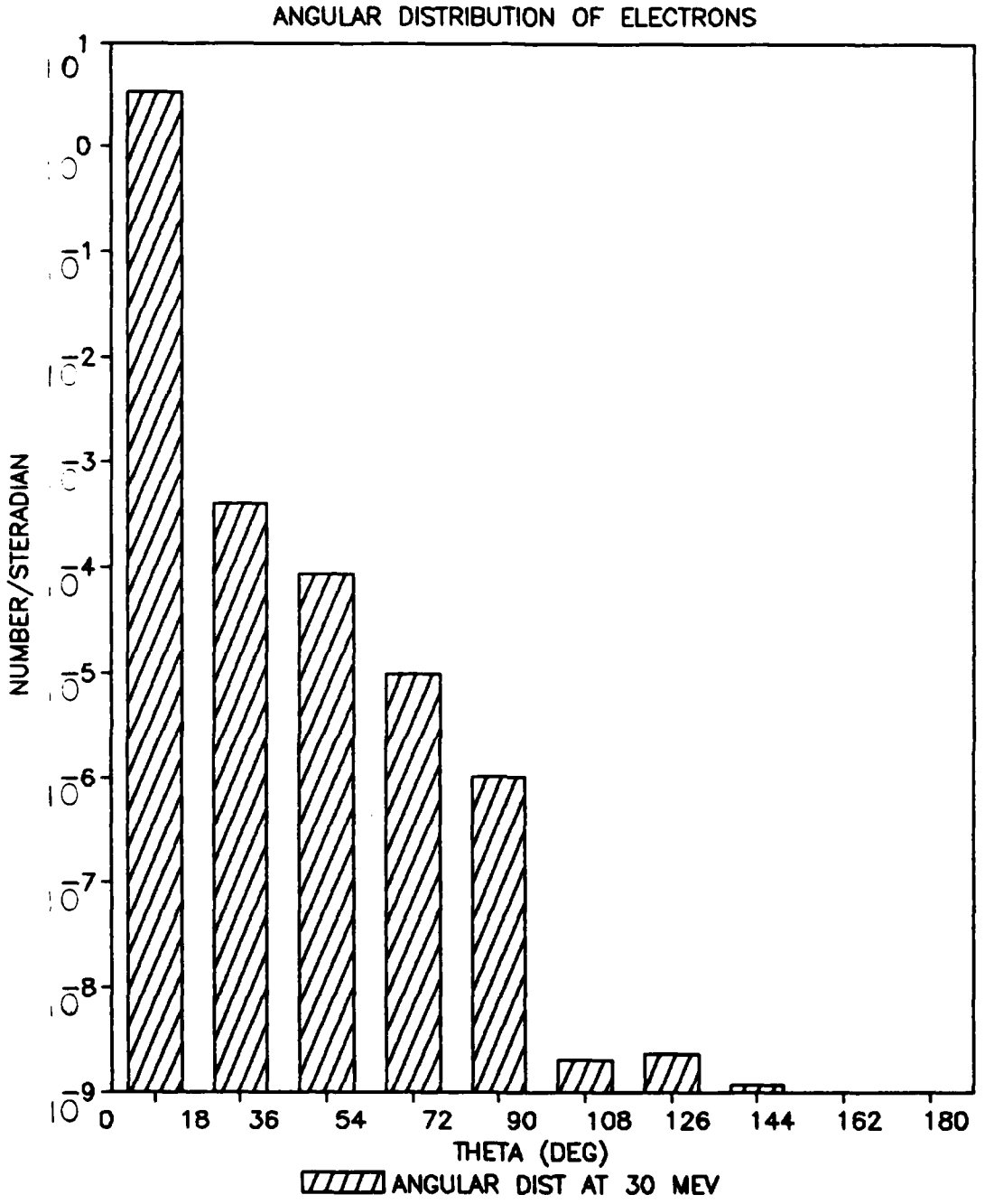


Figure 2.2. Computer simulation of angular distributions of transmitted and reflected electrons normalized to one incident 30 MeV electron.

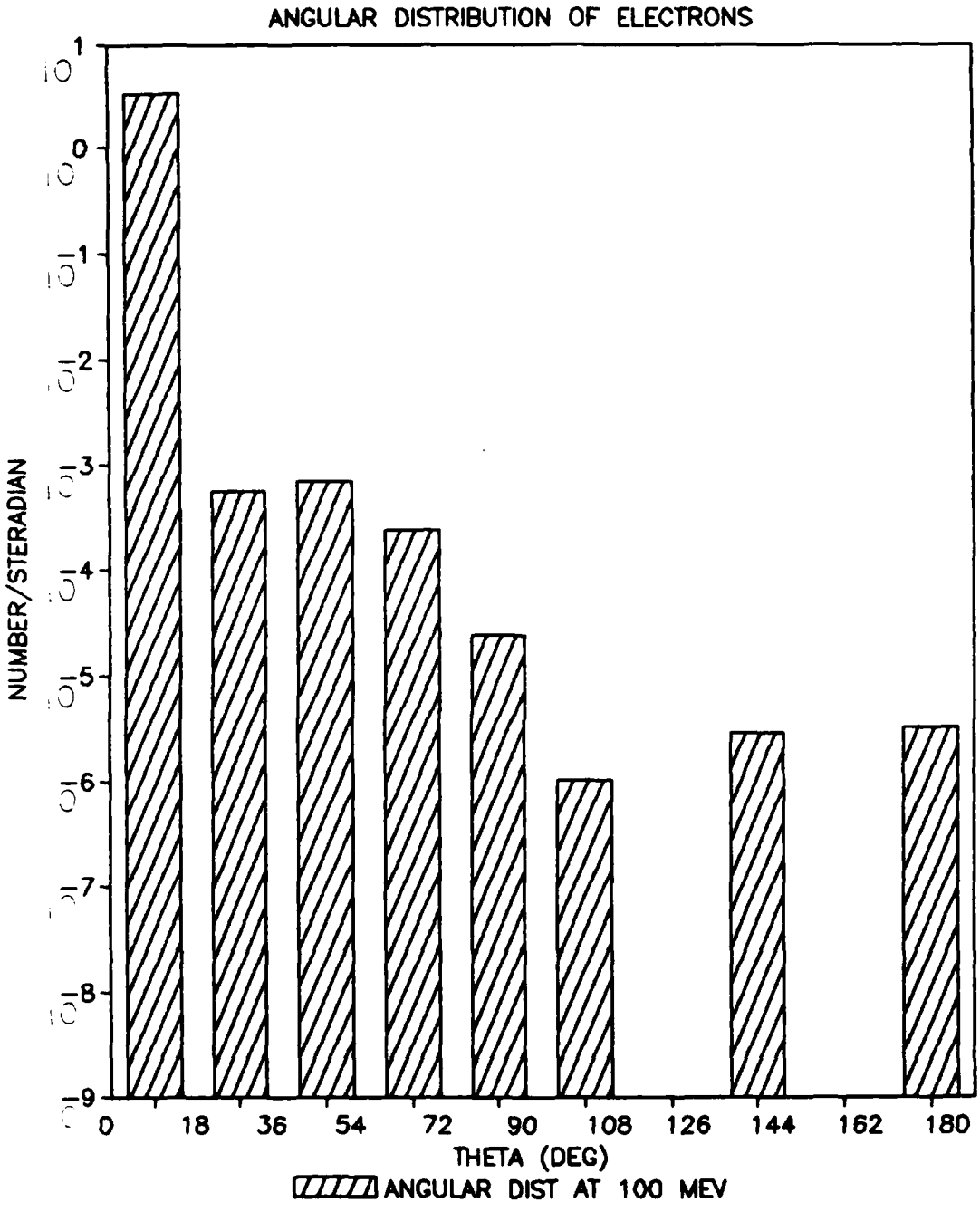


Figure 2.3. Computer simulation of angular distributions of transmitted and reflected electrons normalized to one incident 100 MeV electron.

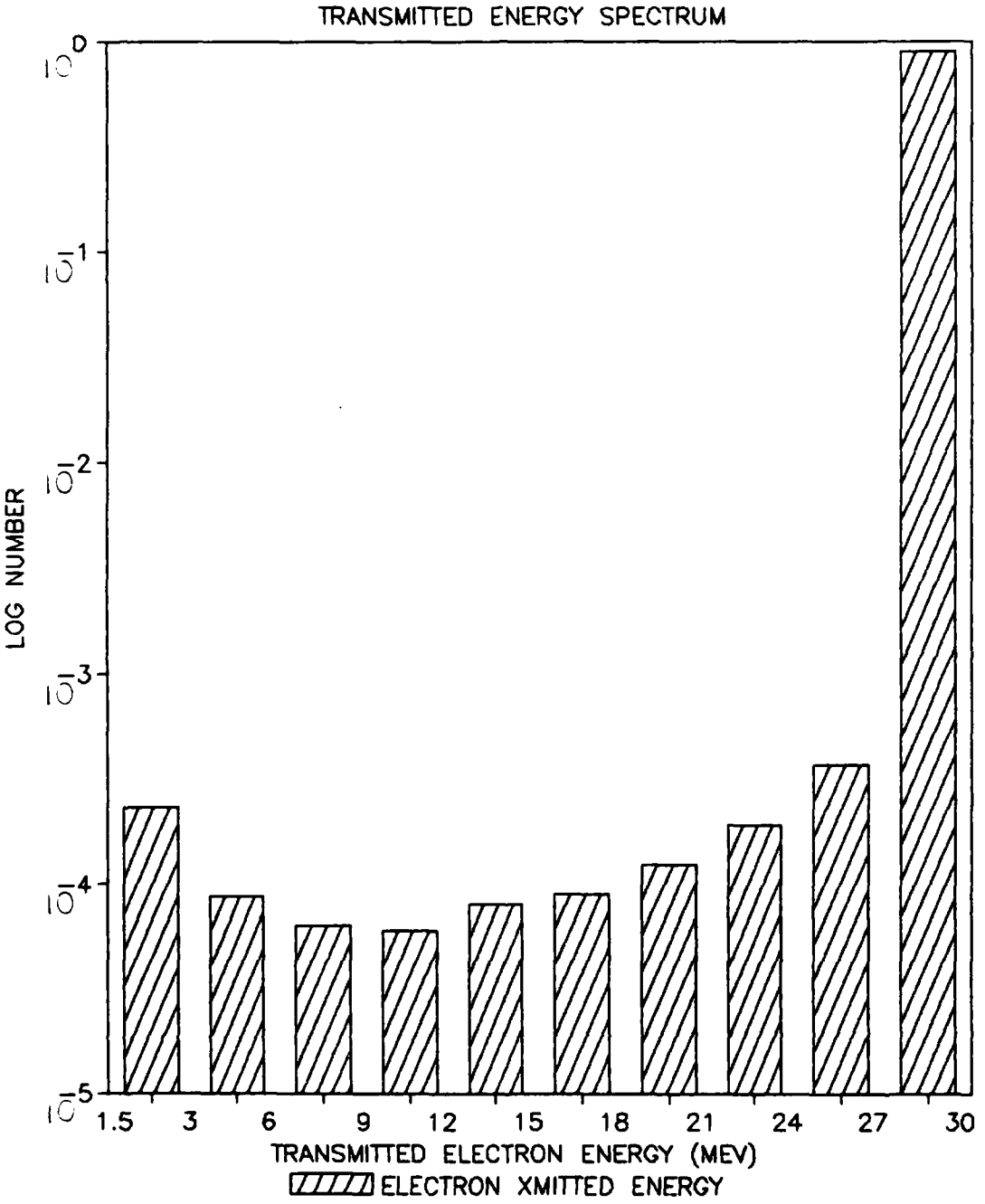


Figure 2.4. Computer simulation of the energy spectra for transmitted electrons normalized to one incident 30 MeV electron.

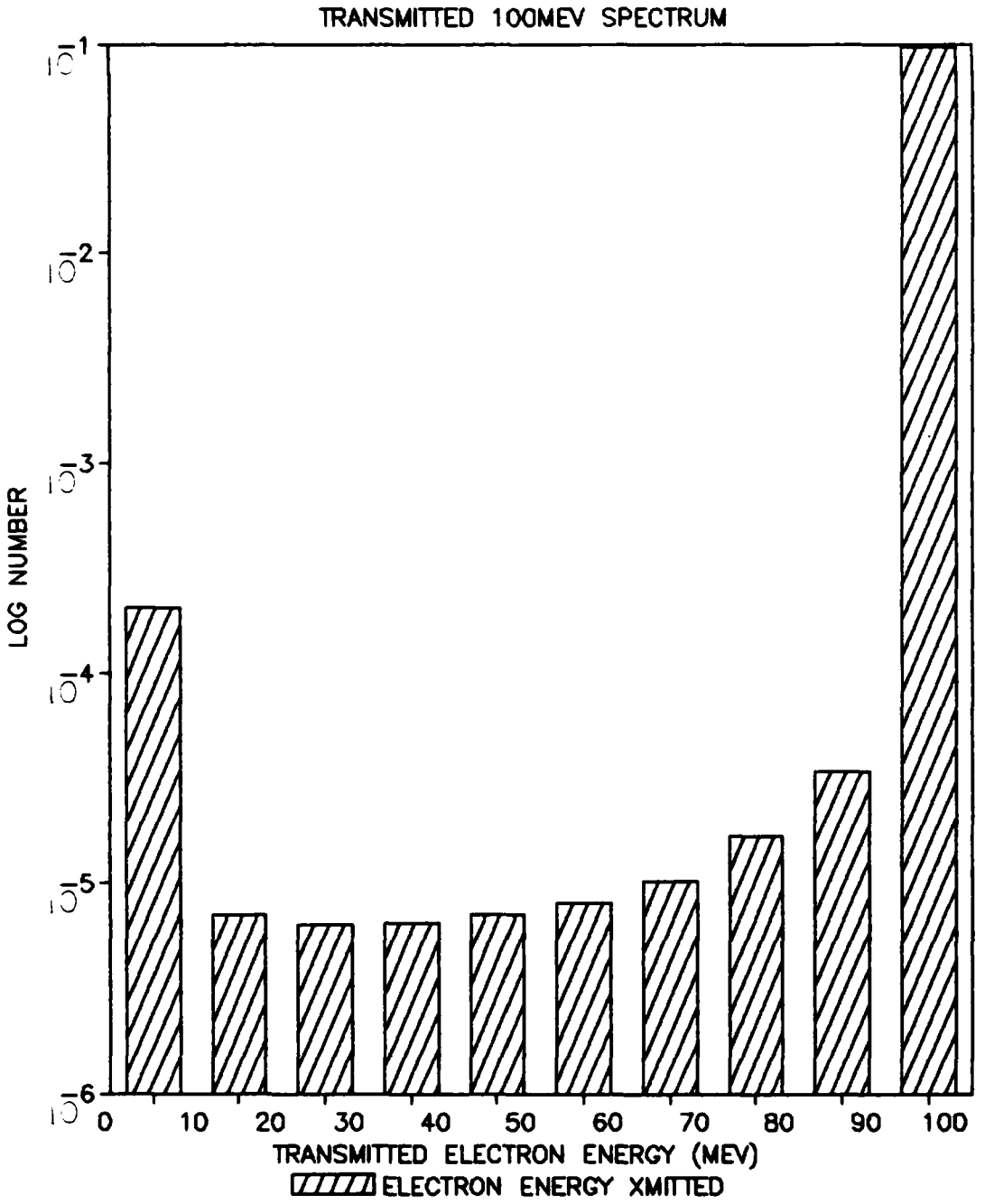


Figure 2.5. Computer simulation of the energy spectra for transmitted electrons normalized to one incident 100 MeV electron.

where,

$$F(\tau) = (1-\beta^2)\left[1+\frac{\tau^2}{8}-(2\tau+1)\ln 2\right] \qquad (2.3)$$

the quantity;

$$.5\left[\ln\left(\frac{T}{I}\right)^2+\ln\left(1+\frac{\tau}{2}\right)+F(\tau)-\delta\right] \qquad (2.4)$$

is the stopping power per atomic electron [Ref. 7].

N ≡ Avagodro's number 6.023×10^{23}

Z ≡ atomic No. of target atoms

I ≡ mean excitation energy mc^2 ≡ electron rest energy

β ≡ velocity of high speed electron/velocity of light

τ ≡ T/mc^2 kinetic energy of incident electron per rest mass

r_o ≡ classical rest energy

A ≡ atomic Wt. of target atoms

The collision stopping power for electrons in Al_2O_3 is 1.75 MeV cm^2/gram for 30 MeV electrons and 1.851 MeV cm^2/gram for 100 MeV electrons [Ref. 7].

2. Radiative Stopping Power

Mass radiative stopping power corresponds to the energy lost by bremsstrahlung. Bremsstrahlung creates a photon as the high energy electron decelerates in the field of an atomic nucleus or atomic electron.

Refinements of Bethe and Heitler's stopping power and scattering theory have led to the following formulation:

$$\frac{1}{\rho}\frac{dE}{dX}_{rad} = \frac{N\alpha r_0^2 Z^2}{A}\left[\phi_{rn} + \left(\frac{1}{Z}\right)\phi_{re}/\phi_{rn}\right] \qquad (2.5)$$

where the ratio ϕ_{re}/ϕ_{rn} is assumed to be unity [Ref.7].

N ≡ Avagodros's number 6.023×10^{23}

Z ≡ atomic No. of target atoms

r_0 ≡ classical electron radius

α ≡ fine structure constant, Z/137

E ≡ T + mc^2 total energy of electron

ϕ_{rn} ≡ scaled radiative energy-loss cross sections for electron-nucleus interaction.

ϕ_{re} ≡ scaled radiative energy-loss cross sections for electron-electron interaction.

A ≡ atomic Wt. of target atoms

3. Dose Measurement

High energy electrons traveling through material are slowed by numerous collisions. The incident electron continuously loses energy and travels a certain range until it comes to rest. Range is defined as the average length of path an electron travels until it is stopped by the medium due to energy loss [Ref. 6].

Dose is a measure of the total amount of energy deposited in the target material. Dose is given in rads (100 ergs/gram) material. The target material must be specified. In this thesis, Al_2O_3 will always be the target material.

Front surface dose for a thin sample will be used. The relativistic electrons of the beam accelerated at 30 MeV and 100 MeV are virtually unaffected by the sample material. The computer model using the Cyltran code shows that 99% of the 30 and 100 MeV electrons bombarding the sample of Al_2O_3, emerge with their initial energy (see Figures 2.4-2.5). Since the energy loss is so small for the electrons, the collision stopping power can be considered a constant.

The energy going into excitation and ionization of the lattice atoms is absorbed in the material close to the track of the bombarding electron. The energy lost by bombarding electrons caused by bremsstrahlung travels far from the electron track before it is absorbed. Front surface dose for a thin sample is expressed by the following formula Eq. (2.6) [Ref. 10].

$$R = 1.6\times10^{-8}\ \Phi\ \frac{1}{\rho}\frac{dE}{dX}_{col}\ \text{rad(material)} \qquad (2.6)$$

$\frac{1}{\rho}\frac{dE}{dX}$ ≡ Collision stopping power for Al_2O_3 [Ref. 7]

Φ ≡ Fluence = electrons/cm^2

C. RADIATION EFFECTS OF ELECTRONS IN INSULATORS

High energy electron irradiation of crystalline insulators introduces changes in the mechanical and physical properties of the insulator. The changes are caused by displacement damage, ionization effects, and excitation of the lattice atoms.

1. Displacement Damage

When an atom is displaced from the lattice, it leaves behind a vacancy in the lattice. If the displaced atom comes to rest in a non-equilibrium position between lattice sites, it is called an interstitial. The energy required to permanently displace an atom is called the displacement threshold energy, E_d. E_d, is 50eV for Al and 90eV for O [Ref. 5].

Displacements are caused when high energy electrons bombard the target material. When a high energy electron enters the material, it collides with the nucleus of a lattice atom. If the collision imparts suffient energy to displace the atom from its lattice site, it creates a vacancy-interstitial pair known as a Frenkel pair.

As a result of the collision, the primary knock-on atom is ionized. The knock-on atom is now a charged particle that continues to move through the insulator losing energy in Coulomb interactions. The coulomb interactions ionize more atoms, creating a cascade of charged particles.

Eventually, all the knock-on atoms come to rest. Some of the atoms will be in interstitial positions, while others recombine with vacancies. The Frenkel pairs form defect clusters due to the small mean free path of the knock-on atoms. The defect clusters may recombine or migrate to a free surface. The defect clusters that migrate

to the free surface are annihilated through annealing. The defect clusters may move throughout the lattice until they form stable displacements. These stable displacements cause the permanent radiation damage observed in insulators.

The number of Frenkel pairs created per incident electron in Al_2O_3 is calculated using the following Equations (2.7-14) [Refs. 8-9]:

$$N_o = \left(\frac{\rho N}{A}\right)\left(\frac{\text{Number of atoms}}{\text{molecule}}\right) \qquad (2.7)$$

$N_o \equiv$ Number of lattice atoms per cm^3

$\rho \equiv$ density of Al_2O_3, 3.97 g/cm^3

$A \equiv$ atomic Wt., 82 g/mole

5 atoms/molecule

$N \equiv$ Avagodro's number 6.023×10^{23}

$$T_m = \frac{2[E+2mc^2]E}{Mc^2} \qquad (2.8)$$

$T_m \equiv$ maximum energy transferred

$E \equiv$ incident electron energy (30 MeV or 100 MeV)

$mc^2 \equiv$ rest mass energy (.511 MeV)

$M \equiv$ atomic Wt. of target atom (Al or O)

$c^2 \equiv$ 931.5 MeV/amu

$$T = E_d\left[\ln\frac{T}{E_d} - 1 + \pi\alpha\right] \qquad (2.9)$$

T ≡ average energy transferred

E_d ≡ displacement threshold energy (50eV Al Or 90ev O)

α ≡ fine structure constant, Z/137

Z ≡ atomic No.

$$\text{Lamda} = \frac{4M_1M_2}{(M_1+M_2)^2} \tag{2.10}$$

where,

Lamda ≡ a scaling factor for the molecule (Al_2O_3)

M_1 ≡ 26.98 (amu) for Al

M_2 ≡ 15.99 (amu) for O

$$\mu(T) = \frac{BT}{E_d} \tag{2.11}$$

B ≡ .5 Kinchin and Pease constant

$$\sigma_D = \frac{2.495\times10^{-24}\,cm^2Z^2}{\beta^4\Gamma^2}\left\{\left(\frac{T_m}{E_d}-1\right)-\beta^2\ln\frac{T_m}{E_d}+\pi\alpha\beta\left\{\left[2\sqrt{\frac{T_m}{E_d}}-1\right]-\ln\frac{T_m}{E_d}\right\}\right\} \tag{2.12}$$

β ≡ v/c

v ≡ speed of electron

c ≡ speed of light

$\Gamma \equiv \sqrt{(1-\beta^2)}$

$\Gamma \equiv E/mc^2$

E ≡ energy of incident electron

$$\sigma_d = \sigma_D\ \mu(T) \tag{2.13}$$

σ_d ≡ total cross section due to primaries and secondaries

$$N_F = \phi_e \sigma_d N_o \qquad (2.14)$$

where,

$N_F \equiv$ No. of Frenkel defects/cm^3

$\sigma_d N_o \equiv$ No. of Frenkel pairs created/incident electron

The calculated value for $\sigma_d N_o$ was 1.017 Frenkel pairs created per electron.

The following assumptions were made when using the previous Frenkel pair equations:

1. If the energy is greater than E_d, displacements will occur.
2. The crystal arrangement of the atoms in the lattice struture is not considered.
3. Annealing is not considered.
4. Atom-atom collisions are treated as hard sphere collisions.
5. Crystal lattice atoms are considered to be stationary.
6. The long range effects of other atoms in the lattice are not considered.
7. Glancing collisions are not considered, even though an energy loss does occur.
8. There is no accounting for ionization loss.
9. The number of replacements per primary atom are not considered.
10. Damage is considered homogenous.

2. Ionization

Ionization is the formation of an ion by the addition or removal of an electron from a neutral atom or

molecule. An electron beam deposits energy in a material by ionizing the lattice atoms of the target material. The ionized atom produces a positive ion and a free electron. The free electrons may ionize other lattice atoms creating secondary free electrons. In addition, the photon processes (photoelectric, Compton effects and pair production) can ionize atoms and produce free secondary electrons.

As the target material is bombarded and ionized, an internal space charge is generated from the trapping of carriers. The space charge sets up a polarized field in the material and an electric field is produced in the insulator. The free electrons, both primaries and secondaries, tend to drift through the insulator under the influence of the electric field. Therefore, an increase in conductivity results.

Some of the secondary electrons will escape from the insulator. The ionized atoms and electrons will slow down and recombine, or be trapped in the impurity sites. Charge carriers trapped at impurity sites alter the electrical properties of the insulator, permanently increasing the conductivity.

The photoelectric effect occurs when an incident photon becomes completely absorbed by the lattice atom, and an atomic electron is removed from the atom. Photoelectric collisions are not important at energies greater than 1 MeV.

The Compton effect results from collisions between photons and atomic electrons. If a photon collides with an atomic electron, it imparts energy to the electron. When the atomic electron absorbs sufficient energy, it leaves the atom and becomes a free electron (called a Compton electron). The incident photon is scattered at a reduced energy. The Compton electron moves through the insulator's crystal structure as a negative charge carrier.

If the Compton electron has an energy greater than 200eV, it can produce displacements and secondary electrons. Ionization of a lattice atom requires 80eV. The Compton electrons constitute what is called a Compton current. In an insulator the Compton current may exceed the dielectric strength of the insulator, resulting in breakdown of the insulator.

3. Pair Production

Incident photons of energies greater than 1.02 MeV can be completely absorbed. In the place of the photon a positron-electron pair is produced, whose total energy is equal to that of the incident photon. This process is called pair production.

4. Electron Excitation

High energy electrons produce electron excitation of the lattice atoms via the coulomb electrostatic field. If the excited electron absorbs enough energy it is ionized. The ionization produces charge carriers. Charge carriers in

insulators recombine or become trapped in defect sites, within approximately 10^{-10} to 10^{-12} secs. Once trapped, the carriers may manifest as permanent changes in the electrical and physical properties of the insulator.

D. CONDUCTIVITY

1. Electrical Conductivity of Al_2O_3

Electrical conductivity of an insulator is much lower than that of a metal at room temperature. The electrical conductivity of sapphire is 10^{-12} $(\Omega\text{-cm})^{-1}$ and 10^{-9} $(\Omega\text{-cm})^{-1}$ for alumina. These values are from 14 to 17 orders of magnitude lower than the nominal value of 10^{5} $(\Omega\text{-cm})^{-1}$ for metals. As the temperature is increased, electrical conductivity decreases in metals. Electrical conductivity increases in sapphire and alumina with increasing temperature. It is obvious that charge carriers in metals are far different than the charge carriers in sapphire and alumina.

Some conduction by electron flow occurs, but the electrons are so tightly bound in Al_2O_3 that they will not move appreciably in an applied field. The charge that is transported is due to the charged ions Al and O. This carrier transport implies a diffusion flow of ions during conduction. Diffusion in sapphire and alumina occurs as the ions move via lattice vacancies. In the absence of an electric field, no net motion of ions takes place because

the probability of motion in any direction is random. The addition of an electric field directs the ions to flow in one direction. The end result is a net transport of both matter and charge.

Since diffusive transport is very small at room temperature, Al_2O_3 exhibits little conductivity. As the temperature increases, diffusion increases causing conductivity to increase. The conductivity and diffusion coefficient, D, are related by Eq. (2.15) [Ref. 11].

$$\sigma = \frac{nZ^2q^2D}{kT} \qquad (2.15)$$

where,

n ≡ number of ions per cubic meter

Z ≡ valence ion

D ≡ diffusion coeffient = D_o exp [-Q/RT]

Q ≡ activation energy

R ≡ gas constant

T ≡ absolute temperature

q ≡ charge

k ≡ Boltzmann's constant

2. Electron Induced Conductivity (EIC) of Al_2O_3

During electron irradiation the sapphire and alumina substrates become conductive. The behavior of the samples is equivalent to a constant capacitor, C, shunted with a resistor, R(t), that varies with time.

The high energy electrons of the beam enter the substrate and lose energy in ionizing collisions with lattice atoms. The ionization creates electrons and holes which generate an avalanche of secondary electrons. While the electrons have sufficient energy, they will continue to cascade, creating more electron hole pairs. The cascading of free electrons is directed when a field is applied, and is called electron induced conductivity (EIC) or radiation induced conductivity (RIC).

The EIC process occurs in the first nanosecond to microsecond of the electron irradiated pulse. High energy particles passing through target materials incur quantum energy losses ranging from 10-30eV [Ref.12]. The quantum energy losses have not been considered in this model. The equations that express RIC are the following:

$$\sigma = N_E q \mu_E + N_H q \mu_H \qquad (2.16)$$

where,

$N_E \equiv$ concentration of free electrons

$q \equiv$ charge

$\mu_E \equiv$ mobility of the electron

$N_H \equiv$ concentration of holes

$\mu_H \equiv$ mobility of the holes

Holes in insulators are usually trapped within a time period of 10^{-4} to 10^{-9} secs. For the purpose of this thesis, holes

will be assumed to be immobile, [Ref. 13] and will be ignored. Eq. (2.16) reduces to:

$$\sigma = Nq\mu \tag{2.17}$$

where,

N ≡ concentration of free electrons

q ≡ charge

μ ≡ mobility of the electron.

RIC is next split into two components σ_p (prompt conductivity) and σ_d (delayed conductivity) expressed in Equations (2.18-2.19) [Ref 13].

$$\sigma = \sigma_p + \Sigma\sigma_d \tag{2.18}$$

$$\sigma_p = K\Gamma^{\delta} \tag{2.19}$$

where,

Γ ≡ Dose rate

K ≡ coefficient for determining the slope of conductivity vs dose rate (obtained from experimental curves [Ref. 1]).

δ ≡ a scaling factor (obtained from experimental curves [Ref. 1])

Delayed conductivity is extremely small and assumed neglible. Delayed conductivity will not be considered in this thesis [Ref. 13].

III. EXPERIMENT

A. SAMPLE FABRICATION

Four devices were fabricated to test the response of EIC. Two of the devices were 30 mil-sapphire substrates and two were 25 mil-alumina substrates. The sapphire used was manufactured by Union Carbide. The alumina was manufactured by Coors. These materials are of high purity developed to meet the needs of the integrated circuit industry. The sapphire and alumina substrates are circular disks measuring 2 cm in diameter.

Photolithographically delineated heaters are incorporated on each side of the sapphire substrate. One side of the sapphire substrate has two electrodes with 3 mil- separation. The electrodes are placed on the heater using an evaporation process. The electrodes of the sapphire substrate are fabricated by evaporating tungsten, molybdenum and titanium onto the substrate.

The alumina samples have one heater photolithographically delineated on one side of the substrate. On the opposite side of the substrate, are two metal electrodes with 3 mil- separation. Tungsten is the first metal put onto the substrate using a sputtering process. The molybdenum and titanium are evaporated onto the alumina substrate.

The substrates are then enclosed by glass envelopes with an eleven pin configuration typical of a vacuum tube. Fig. 3.1 is a photograph of the EIC test device. The samples are processed using the normal vacuum bakeout and activation cycle [Ref 1].

B. PRE-IRRADIATION AND POST-IRRADIATION MEASUREMENTS

The optimum EIC test device temperature, determined by Los Alamos National Laboratory, is 1073 K [Ref. 1]. The test device heater voltage was determined by measuring the temperature heater substrate with an optical pyrometer. The temperature readings were accurate to ±5 K.

Steady state resistance and conductivity of the Al_2O_3 samples were determined by plotting current vs voltage curves. The initial and post-irradiation resistance data was measured using a Keithley 617 electrometer, as shown in Fig. 3.2.

C. NPS LINAC

The Naval Postgraduate School (NPS) linear accelerator (LINAC) is a traveling wave type machine. It is patterned after those built at Stanford University in the early 1950's. The LINAC is a disk loaded circular wave-guide thirty feet long, constructed in three ten foot sections. It consists of a series of three klystrons used to accelerate electrons to relativistic energies from 15 MeV to 100 MeV.

Figure 3.1. Sapphire substrate enclosed by glass vacuum tube.

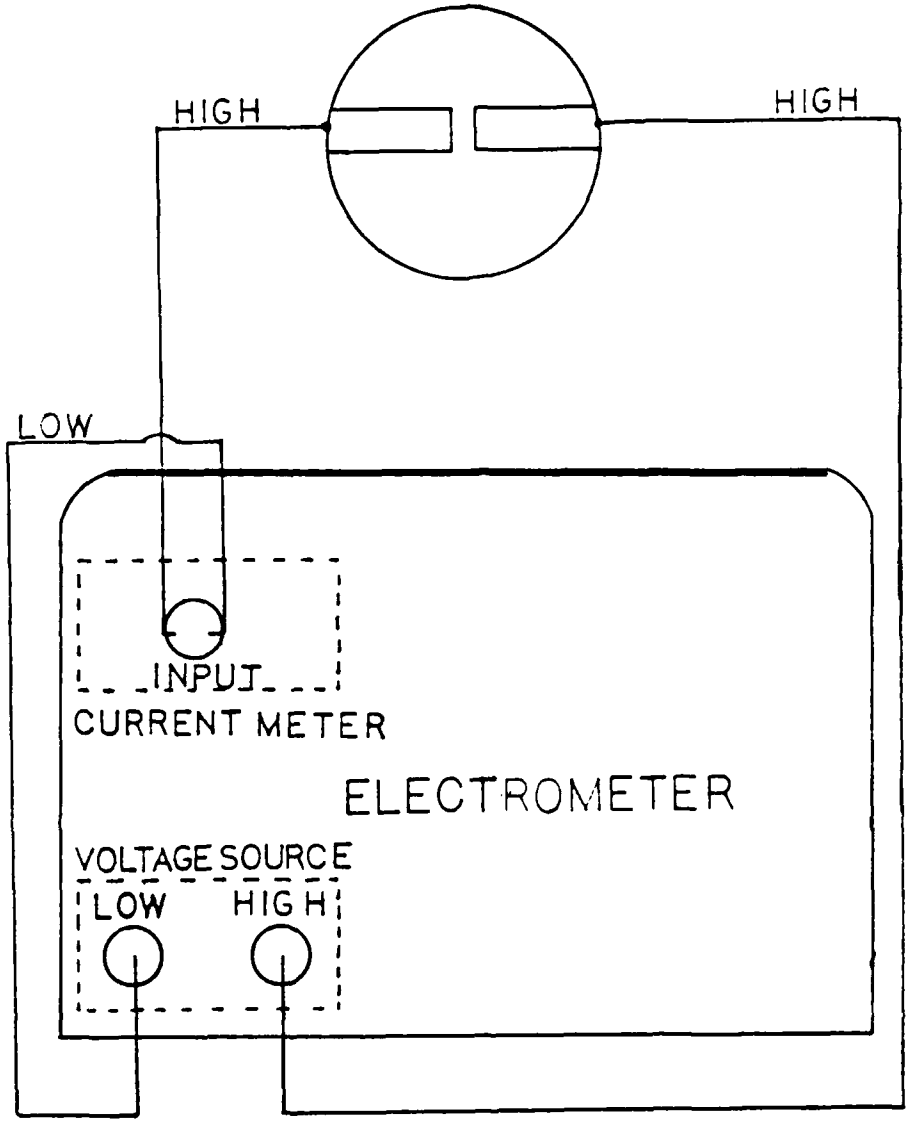


Figure 3.2. Test equipment set up for current vs voltage measurement across the substrate.

EIC experiments conducted using 30 MeV electrons utilized only one klystron. The experiments conducted using 100 MeV electrons required all three klystrons. The LINAC pulses sixty times per second with a 1-μsec pulse.

Relativistic electrons are focused on a target which is placed inside the target chamber, (held at a vacuum of 1-μtorr) or just outside the target chamber. Targets placed outside the target chamber are placed as close as possible to the target chamber window (a thin aluminum plate). The electron beam is focused and shaped using deflection and focusing magnets.

Electron fluence is measured utilizing a secondary emission monitor (SEM) located inside the target chamber. As electrons strike the SEM, a capacitor is charged and voltage is measured across the capacitor using a voltage integrator circuit. This charge relationship is given by the following equation:

$$Q_S = CV \tag{3.1}$$

where Q_S is the toltal SEM charge, C is the capacitance and V is the accumulated voltage. The total beam charge that has passed through the SEM is determined using:

$$Q_B = Q_S/0.026 \tag{3.2}$$

where Q_B is the total beam charge.

Previous research on scattering experiments used a Faraday cup to calibrate the large SEM. Efficiency for the

large SEM was found to be 6% [Ref. 14]. The Faraday cup has since been removed and the large SEM has become the standard.

The small SEM used in this thesis was calibrated against the large SEM. Efficiency for the small SEM is 2.6%. Thus 0.026 is the efficiency factor used in Eq. (3.2). Using Eq.'s (3.1) and (3.2) the total number of beam electrons, (N), is given by

$$N = CV/0.026q \tag{3.3}$$

where q is the charge of an electron.

Fluence is determined by dividing both sides of Eq. (3.3) by the area A. Fluence is the number of electrons per unit area of the beam expressed as

$$\Phi \equiv \text{Fluence} = CV/0.026qA \tag{3.4}$$

D. TEST PROCEDURE

The EIC test device was installed in its test fixture as shown in Fig. 3.3. The device was heated to its correct temperature by monitoring the heater voltage. The sample was heated very slowly, approximately 1Volt/min, to prevent thermal shock to the substrate. Once the correct heater voltage was obtained, the device was allowed to bake for at least fifteen minutes prior to irradiation. During the baking period a fluorescent target equal in height with the substrate was placed on the test fixture. For these EIC

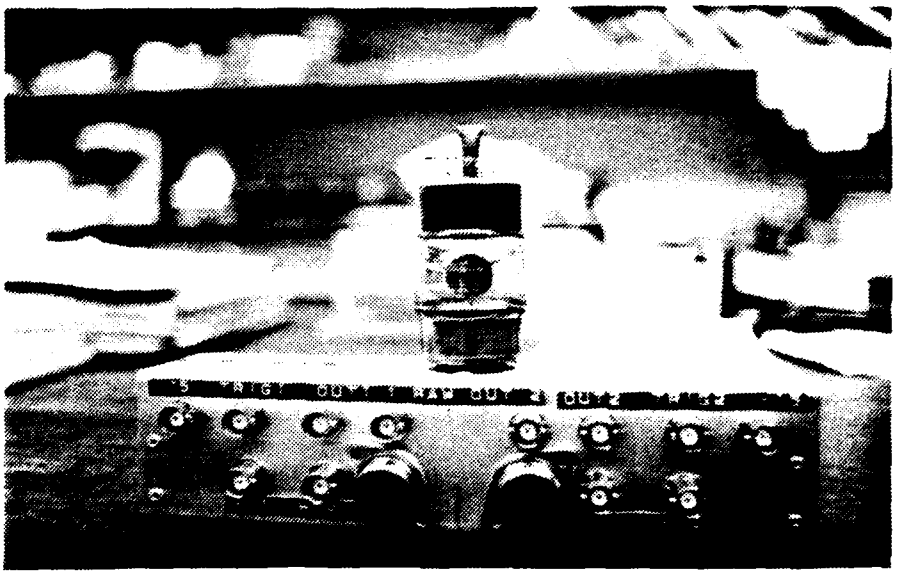


Figure 3.3. EIC test device plugged into its test fixture.

experiments the test device and test fixture were placed just outside the vacuum test chamber window.

The electron beam was focused on the fluorescent target. Video cameras monitored the fluorescent target and relayed the picture to the control room. The electron beam appears as a very bright area on the fluorescent target. In the control room the electron beam is adjusted and focused into a circular disk of 1 cm^2. A circle is drawn on the video monitor around the electron beam.

The electron beam was shut off and the test device was positioned as close to the target chamber window as possible, (there was approximately a 5mm gap between chamber and tube) directly in front of the electron beam.

The EIC experiment consisted of the following steps:

1. A bias voltage was applied (0-250 volts positive. 0-(-100) volts negative) across the EIC metal electrodes.

2. The device was irradiated using 30 MeV or 100 MeV electrons. The irradiation time was from 20 to 30 secs.

3. The responce was viewed with an oscilloscope. The device response was recorded by photographing the oscilloscope CRT.

4. The beam was shut off for 1-3 minutes to allow the internal space charge to dissipate.

5. A new bias voltage was applied and steps 1-4 repeated.

Attempts to dissipate internal space charge by removing the applied field and irradiating the device for several seconds were unsuccessful. This process annihilated about

70% of the internal space charge. The only way to annihilate all the internal space charge was to shut off the electron beam and allow the space charge to dissipate.

IV. DATA AND RESULTS

A. STEADY STATE RESISTIVITY AND CONDUCTIVITY

Pre-irradiation and post irradiation measurements of steady state current and voltage were made for the sapphire and alumina substrate samples. The plots of these current vs voltage measurements are illustrated in Figs. 4.1-4.2. Resistivity was determined by computing the inverse slope of the curves. Conductivity (σ) was calculated using the following equations:

$$\sigma = \frac{\ell}{RA} \tag{4.1}$$

$$\sigma = \frac{\ell}{RLt} \tag{4.2}$$

$$\sigma = \frac{1}{RL(t/\ell)} \tag{4.3}$$

where,

ℓ ≡ distance of separation between the electrodes (3mils)

L ≡ width across the electrode (29.7mils)

R ≡ resistivity

t ≡ carrier penetration depth into the substrate

$\frac{1}{t/\ell}$ ≡ .624, a scale factor calculated using a Laplace equation computer program. R. Dooley of Los Alamos National Labratory determined the scale factor. Fig. 4.3 illustrates the conductivity calculation geometry.

Steady state pre-irradiation and post-irradiation data is presented in Table 4.1.

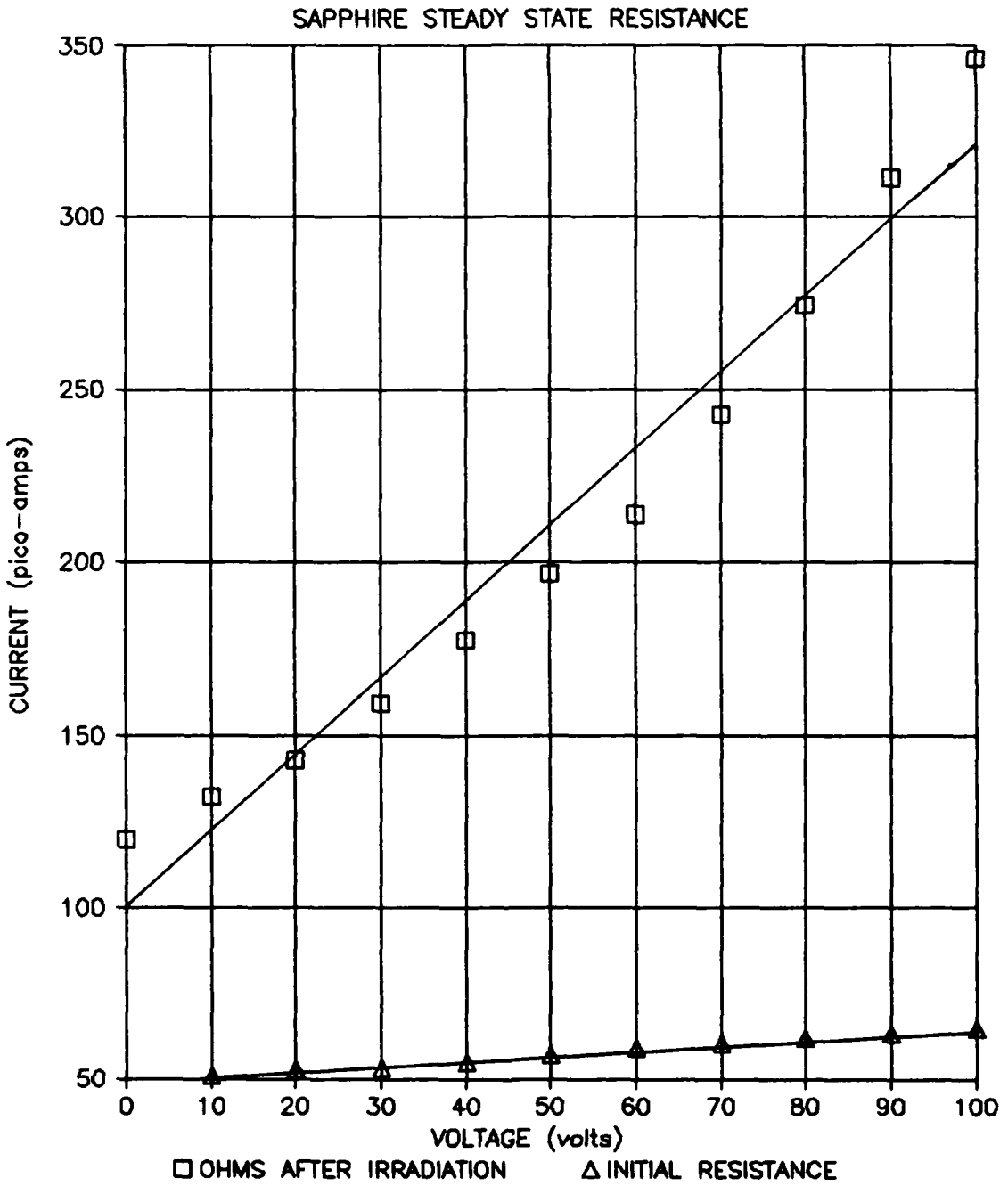


Figure 4.1. Current vs voltage plots before and after electron irradiation of sapphire. Resistivity is the slope. Initial resistivity was 6.36×10^{12} (Ω-cm) and resistivity after irradiation was 4.5×10^{11} (Ω-cm).

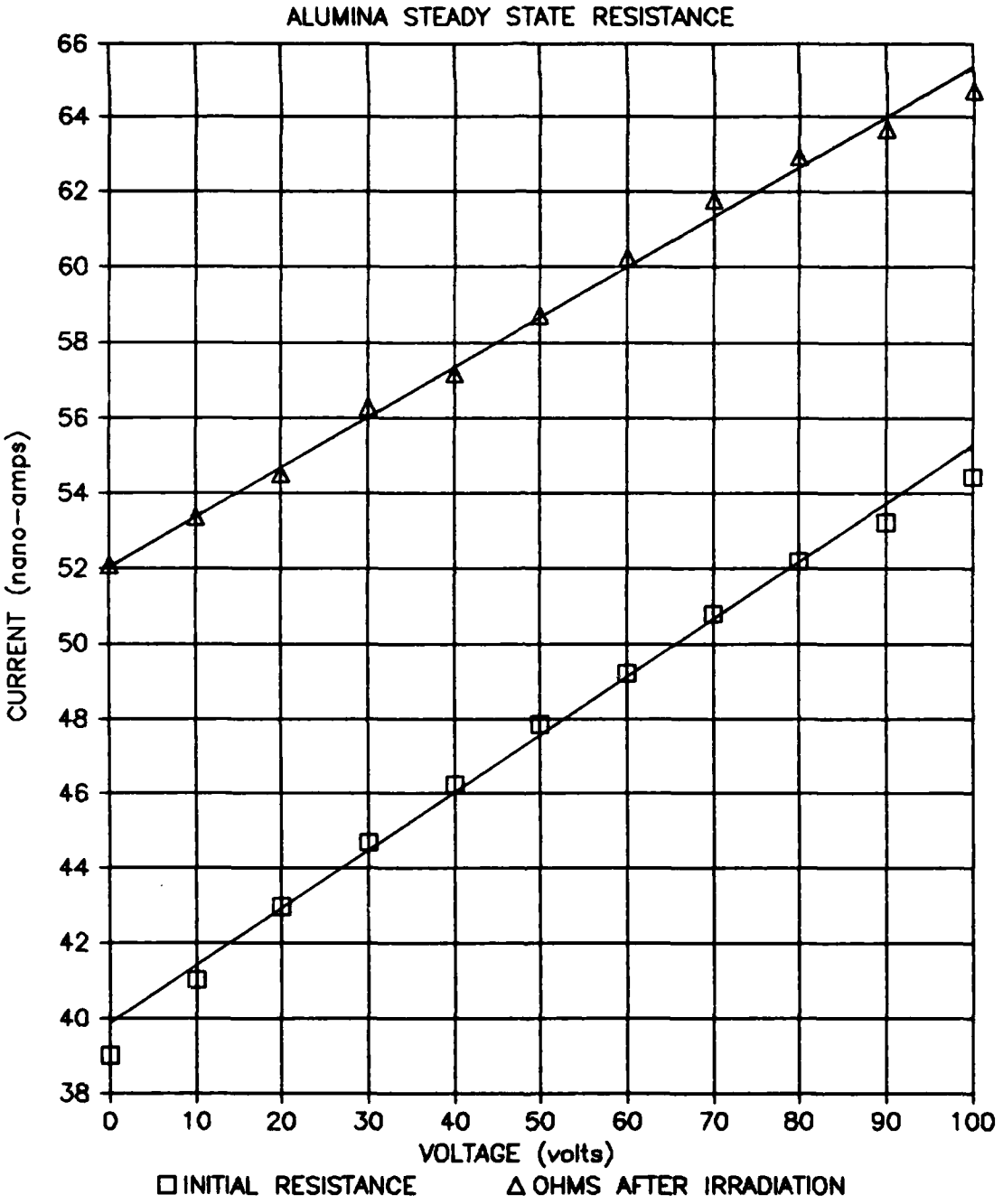


Figure 4.2. Current vs voltage plots before and after electron irradiation of alumina. Resistivity is the inverse slope. Initial resistivity was $6.29 \times 10^{+9}$ (Ω-cm) and resistivity after irradiation was $7.60 \times 10^{+9}$ (Ω-cm).

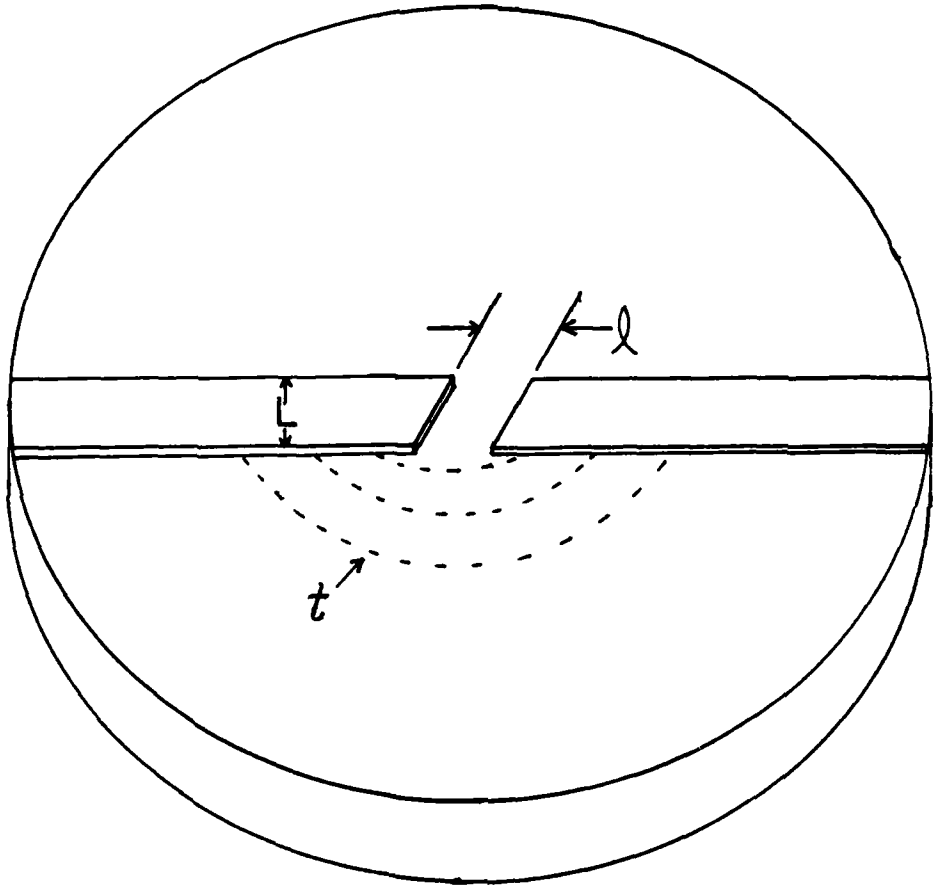


Figure 4.3. Conductivity calculation geometry of a sample substrate with two electrodes a distance ℓ apart.

TABLE 4.1. CHARACTERISTIC VALUES FOR SAMPLES SAPPHIRE AND ALUMINA

	Pre-Irradiation		Post-Irradiation		30 MeV Irradiation	
	Sapphire	Alumina	Sapphire	Alumina	Sapphire	Alumina
Resistivity (Ω-cm)	6.36×10^{12}	6.29×10^{9}	4.50×10^{11}	7.60×10^{9}		
Conductivity $(\Omega\text{-cm})^{-1}$	1.30×10^{-12}	1.31×10^{-9}	1.84×10^{-11}	1.78×10^{-9}		
EIC $(\Omega\text{-cm})^{-1}$					1.85×10^{-3}	2.81×10^{-4}
Fluence (elec/cm²)			1.77×10^{15}	2.67×10^{15}	1.77×10^{15}	2.67×10^{15}
Flux (elec/cm²-s)			2.08×10^{15}	5.20×10^{14}	2.08×10^{15}	5.20×10^{14}
Dose rads(Si)			5.14×10^{7}	7.72×10^{7}	5.14×10^{7}	7.72×10^{7}
Dose rate rads(Si)/s			6.02×10^{7}	1.51×10^{7}	6.02×10^{7}	1.51×10^{7}

B. TRANSIENT EIC

The sapphire and alumina substrates were irradiated using 30 MeV electrons. The fluence varied from 10^{14} to 10^{15} electrons/cm^2. The dose rate was 10^7 rad(Si)/sec. Transient EIC is shown by the photograph in Fig. 4.4. The transient EIC at various bias voltages is presented in Appendix A.

In Fig. 4.4 the measured voltage (Vx) is along the y-coordinate and time is along the x-coordinate. The straight heavy white line at the lower left corner is the zero reference line for the electron beam response. The fuzzy line immediately following the zero reference line is assumed to be carried by noise from the electron gun, and is ignored. Vx is measured from the zero point to the peak of the white line trace. In this picture Vx is 18mV ±0.5mV. Vx changes as bias voltage is changed.

In both sapphire and alumina, an increase in positive bias voltage increased Vx. A bias voltage of 150 volts gave the maximum Vx for sapphire. As the bias voltage was increased from 150-250 volts a large decrease in Vx was observed. A limiting peak of Vx was not observed in alumina, as the voltage was increased to a maximum of 250 volts bias.

Then a negative bias was applied, sapphire and alumina showed a decrease in Vx. For alumina, Vx was zero when a bias voltage of -110 volts was applied. Vx was zero in

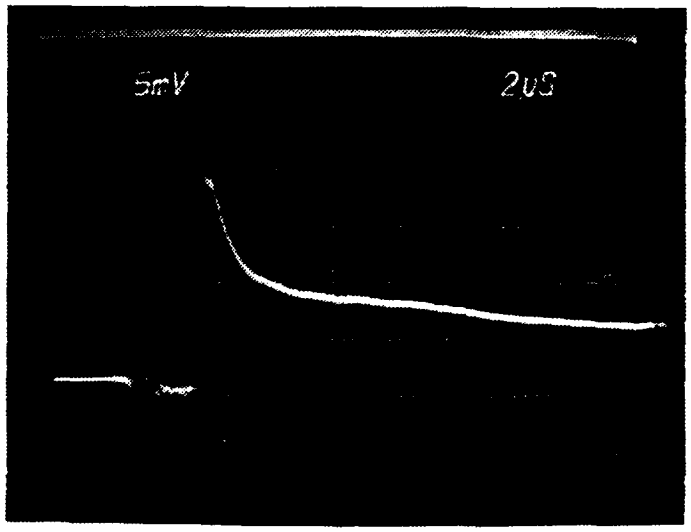


Figure 4.4. Sample photograph of alumina irradiated with 100 MeV electrons.

sapphire when a bias voltage of -22 volts was applied. Photographs in Appendix A illustrate these findings.

EIC was determined in the following way. A plot was made of Vx vs bias voltage, see Figs. 4.5-4.6. The slope of this curve was computed. The slope was used in the following equation:

$$\Delta \underline{Ix} = \underline{\text{slope}} \qquad (4.4)$$
$$\text{Vbias sensing resistor}$$

where the sensing resistance was 50 Ω.

ΔIx ≡ change in current

Vbias ≡ applied bias voltage

Resistivity was found by taking the inverse of Eq. (4.4). EIC was calculated using the resistivity from Equations (4.1-4.3). The EIC data is presented in Table 4.1.

C. DOSE RATE CALCULATIONS

Dose rate was determined using the following equations.

$$Q = \frac{\langle I \rangle \text{ beam current}}{\text{Number of pulses/sec}} \qquad (4.5)$$

$$\dot{\Phi} \equiv \text{Flux} = \frac{Q \text{ (coulombs/sec)}}{\text{Area } (1.602\times10^{-19}) \text{coul/electron}} \qquad (4.6)$$

$$\dot{\Phi} = \frac{\text{electrons}}{\text{cm}^2\text{-sec}} \qquad (4.7)$$

$$\dot{\Gamma} = 1.6\times10^{-8}\ \Phi\ \frac{1}{\rho}\frac{dE}{dX}_{col}\ \frac{\text{rads(material)}}{\text{sec}} \qquad (4.8)$$

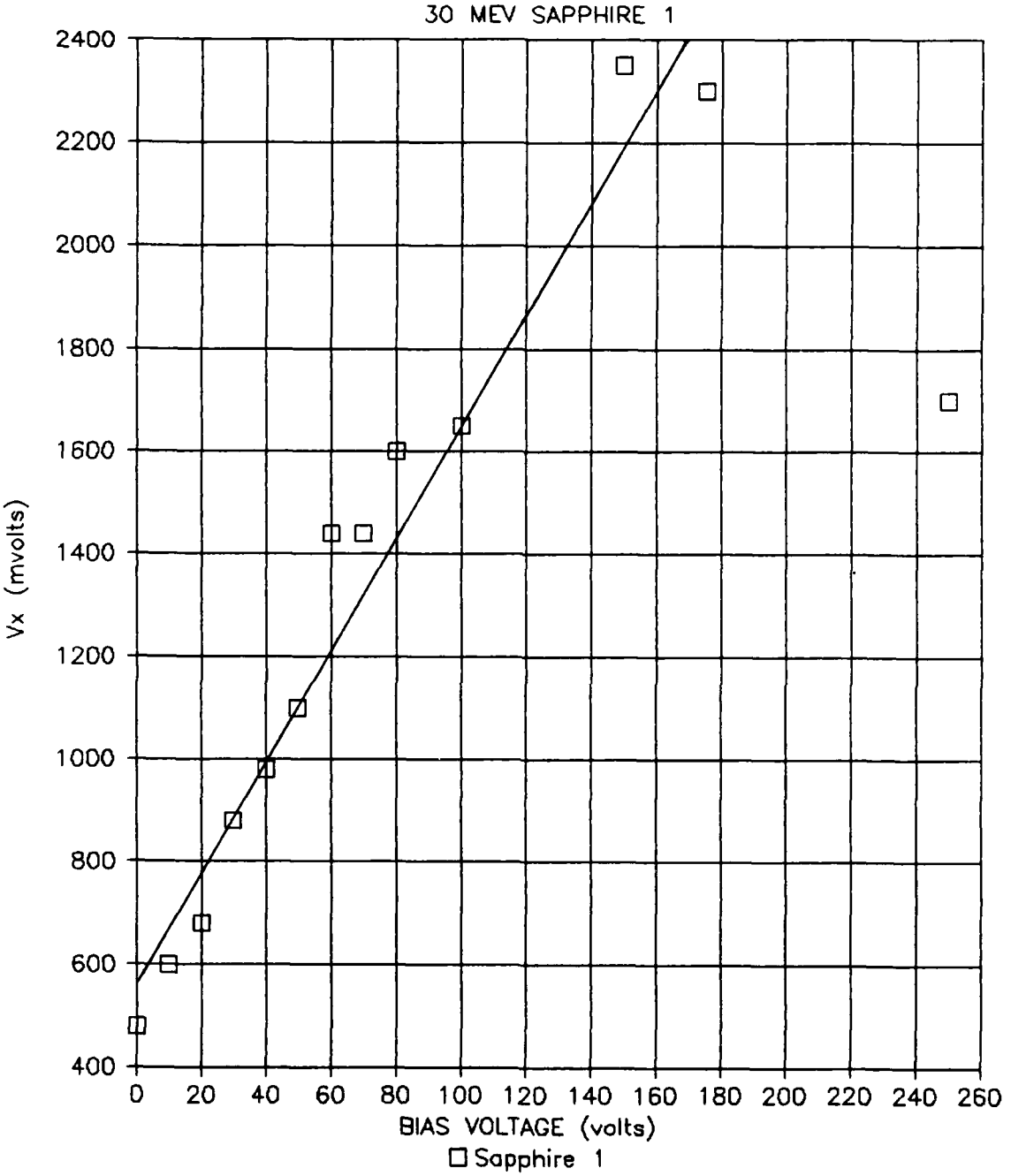


Figure 4.5. Changes in measured voltage (Vx) vs bias voltage for a sapphire sample.

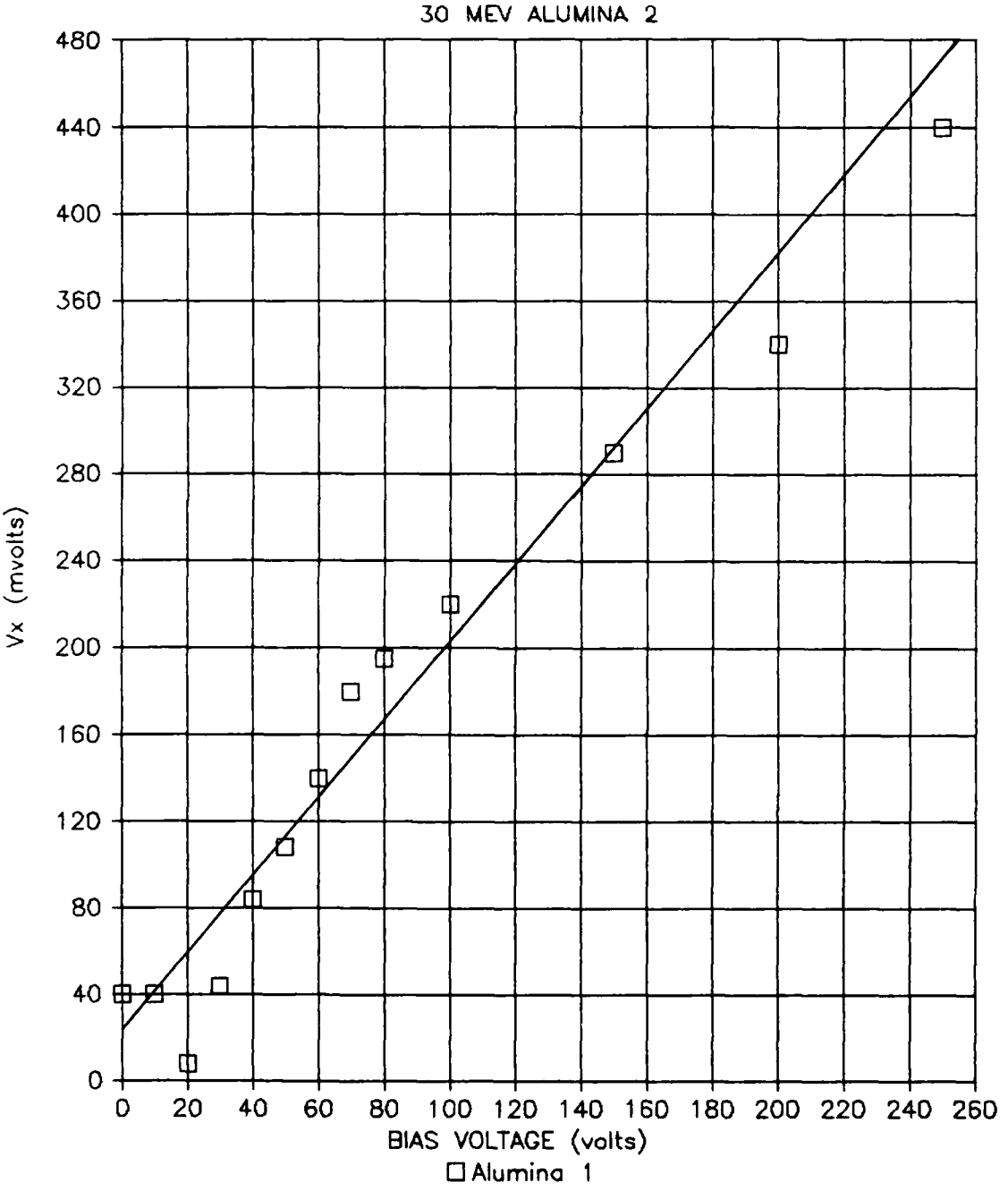


Figure 4.6. Changes in measured voltage (Vx) vs bias voltage for an alumina sample.

where, Eq. (4.8) is a variation of Rudi's dose Eq. (2.6) [Ref. 10] and $dE/\rho\, dX$ is the stopping power [Ref.7].

In radiation effects, damage is normally scaled to silicon. A scaling factor is determined by dividing the silicon stopping power by the stopping power of the sample material, using the same electron beam energy. The scaling factor for aluminum oxide (Al_2O_3) at 30 MeV is 1.034. A typical calculation of dose rate, using $\langle I \rangle = 2\times10^{-8}$ amps, yields a flux of 2.08×10^{11} electrons/cm^2-sec. The calculated dose rate is 6.02×10^{7} rads(Si)/sec.

V. DISCUSSION OF RESULTS

The sapphire sample #2, was irradiated using 100 MeV electrons. The heater substrate had more than 25 very small holes distributed throughout the substrate. The holes did not interfere with actual heater operation. The sample was activated to a heater temperature of 1073 K, three times prior to irradiation.

Upon initial irradiation sapphire #2 displayed the characteristic EIC trace on the oscilloscope (see Appendix A for photographs). After about 20 minutes of continuous electron bombardment, the EIC trace no longer showed a characteristic Vx. The trace displayed fuzzy negative peaks.

The response of the device shows a breakdown of the substrate. The sapphire substrate broke down at a positive bias of about 30 volts. The dose rate at the time of breakdown was 1.28×10^{9} rads(Si)/sec. The substrate appears to have broken down due to surface flashover.

Surface flashover is generated when a high voltage is applied across an insulator [Ref. 15-16]. The 100 MeV electron irradiation of sapphire #2 produced a large voltage applied through electrodes across the substrate. As the substrate absorbs the electron beam energy, a surface charge begins to form. A cascade of secondary electrons generates

a secondary emmission of thermalized electrons. These thermalized electrons in turn increase both surface charge and internal space charge. A low resistance breakdown path formed across the substrate because the substrate heater had holes, and substrate breakdown occured.

Surface flashover did not occur in the other sapphire and alumina samples. There was no low resistance breakdown path available in the other samples. The other substrate samples stabilized and a large space charge was observed.

Relativistic electrons produce a uniform distribution of electrons and holes in radiated material. In EIC experiments, two metal electrodes A and B on the substrate material ensure a path for electron flow, see Fig 3.2. As the electron beam strikes the substate, free electrons are generated inside the bulk material.

The free electrons are swept out almost immediately, in about 1 picosecond, by the self-induced electric field. The ocilloscope shows a large negative trace with a fast rise time of 0.5 μsec. The trace exponentially decays and returns to the zero reference line. This behavior demonstrates the large polarization due to internal space charge.

Holes are left in the substrate and they migrate while annealing takes place. The time period of annealing is from miliseconds to as long as days.

As the positive bias voltage is increased, more electrons are swept from electrode A across the substrate

and out of electrode B. The trace on the oscilloscope shows a large positive increase in Vx. The EIC follows the rise time of the radiation pulse then decays exponentially, similar to a capacitor.

When a negative bias voltage is applied, a large positive trace on the oscilloscope is observed. The positive trace becomes more negative as the negative bias is increased. The EIC current was smaller in magnitude when a negative bias was applied. Positive bias causes a greater EIC current magnitude because EIC thermalized electrons add to the positive bias voltage electrons. When negative bias is applied EIC current acts as a barrier to the applied negative bias voltage. The result is a smaller magnitude for the measured voltage Vx.

The response exhibited by a capacitor shunted by a resistance R(t) which varies with time, is very similar to the behavior of the substrates. Oscillogram photographs in Appendix A illustrate the different EIC measured values for the different applied bias voltages.

Plots of Vx vs bias voltage, (Figs. 4.5-4.6) clearly show a linear relationship. Van Lint et al. Face, et al. and Pomerantz et al. [Refs. 13,17,18] observed this same linear relationship.

At 1073 K, annealing of radiation damage in TIC can be virtually ignored. Any annihilation through annealing of displacement clusters is an on going process at TIC

operating temperatures. The annealing of radiation damage is incorporated during the irradiation and is not observed.

As electrons bombard a sample more traps form and recombinations take place. As dose accumulates, the dose rate response should exhibit some change. Neither sapphire or alumina exhibited change as the dose accumulated for a given dose rate. Arguello observed instead, that TIC triode circuit characteristics stabilized as dose increased to 1.86×10^{7} rads(Si) [Ref.19].

There was no significant difference recorded when bombarding alumina with 100 MeV electrons or 30 MeV electrons (see Appendix A). This is not surprising since collision stopping powers between 100 MeV electrons and 30 MeV electrons vary by only 0.1 MeV cm^2/gram.

EIC for sapphire was experimentally determined to be 1.85×10^{-9} $(\Omega\text{-cm})^{-1}$ at a dose rate of 6.02×10^{7} rads(Si)/sec. Alumina EIC was 2.81×10^{-4} $(\Omega\text{-cm})^{-1}$ at 1.51×10^{7} rads(Si)/sec. Using Eqn. 2.19 with $K=7.7 \times 10^{-13}$ and $\delta=1$, the prompt conductivity for an undoped Linde crystal is $\approx 10^{-4}$ $(\Omega\text{-cm})^{-1}$ [Ref. 1]. This value is $\approx$ 2 orders of magnitude different than the experimental values calculated for sapphire and alumina. Since K is a function of ionization and varies according to electron-hole pair recombination, K can change by orders of magnitude. The crystalline structure, traps and impurities generated during manufacture all contribute to the values of K.

VI. CONCLUSION

Electron induced conductivity (EIC) is an important damage mechanism in integrated circuits. EIC can cause single-event upset in critical electronic components of weapon systems, communication systems and navigational systems. Thermionic integrated circuits (TIC) are orders of magnitude more resistant to total dose radiation than any other integrated circuits available. To ensure TIC devices are more resistant to single event upset, materials used in the substrates must have the lowest EIC possible.

Experiments were conducted to observe the EIC in undoped single crystal sapphire (Al_2O_3) and undoped poly-crystalline alumina (Al_2O_3). The Naval Postgraduate School's linear accelerator provided 30 and 100 MeV electrons. The high energy electrons provided a maximum dose rate of 1.28×10^{13} rads(Si)/sec. The experimentally determined EIC for sapphire was 1.85×10^{-13} $(\Omega\text{-cm})^{-1}$ when bombarded at a dose rate of 6.02×10^{7} rad(Si)/sec. Using a dose rate of 1.51×10^{7} rad(Si)/sec the experimentally determined EIC for alumina was 2.81×10^{-14} $(\Omega\text{-cm})^{-1}$.

Alumina was an order of magnitude more resistant to EIC than sapphire. The EIC characteristics of sapphire and alumina remained unchanged as the total dose increased. Alumina was irradiated using 30 and 100 MeV electrons. The

EIC results using 100 MeV electrons did not differ from the results when 30 MeV electrons were used.

Alumina, being a naturally disordered and opaque material, exhibited greater radiation hardness than sapphire. The processing of devices, of thickness less than 20-mils, is easier for sapphire than alumina.

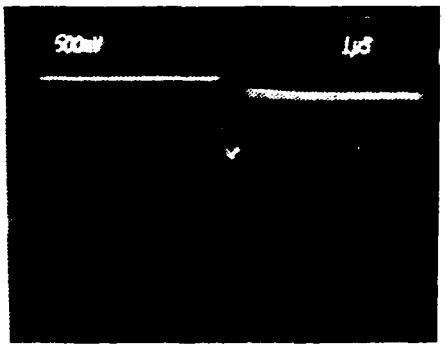
Further radiation studies should be conducted using TIC devices. If the processing problems presented by alumina cannot be overcome, other materials must be tested. Radiation studies should be conducted using doped sapphire. Doping sapphire should enhance radiation hardness and decrease radiation induced conductivity.

TIC devices show great promise for use in hostile radiation environments. The use of alumina for the substrate of these devices ensures they will be as resistant to single event upset as possible.

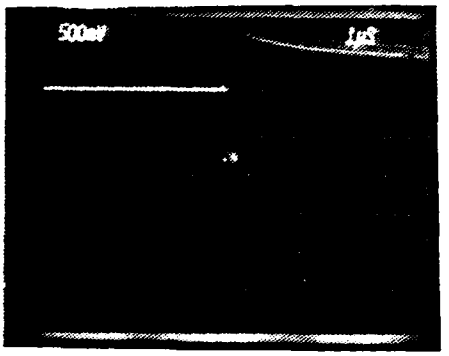
APPENDIX A

ELECTRON INDUCED CONDUCTIVITY PHOTOGRAPHS:

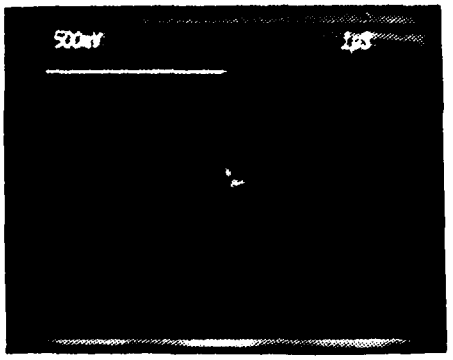
Enclosed are photographs of electron induced conductivity (EIC), for sapphire and alumina irradiated with 30 MeV and 100 MeV electrons. The photographs are presented from left to right. Time is along the x-coordinate and the measured value (Vx) is along the y-coordinate. The straight heavy white line, located at the lower or upper left hand corner of the photographs, is the zero reference point. After the zero reference point, a fuzzy line normally appears, this is assumed to be caused by the electron gun, and should be ignored. Vx is measured from the baseline to the peak of the white line trace. Under each photograph the measured value, Vx, is designated along with the corresponding bias voltage.



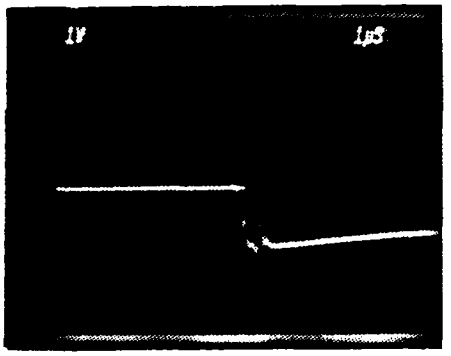
Vx = 650mV at OV bias



Vx = 1650mV at 10v bias

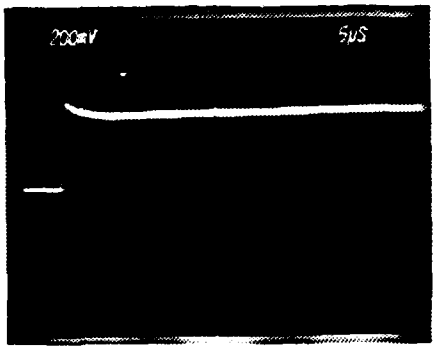


Vx = 2000mV at 20V bias

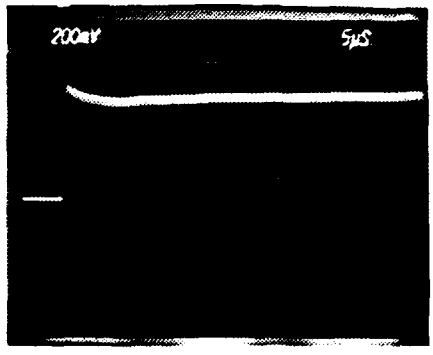


Breakdown at 30V bias

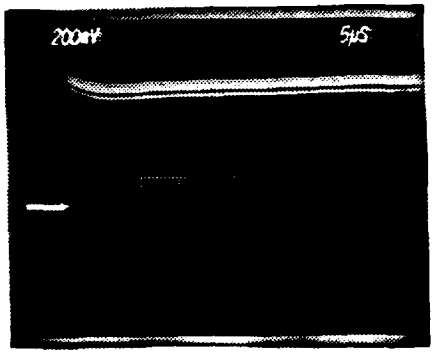
Figure A1.1. Photographs of sapphire #2 irradiated with 100 MeV electrons.



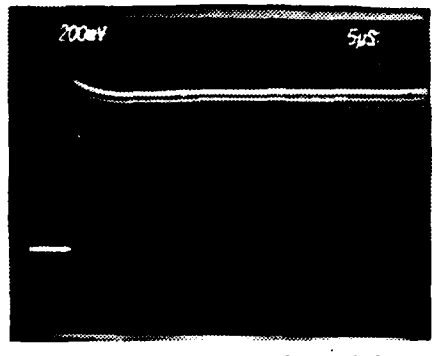
Vx = 480mV at OV bias



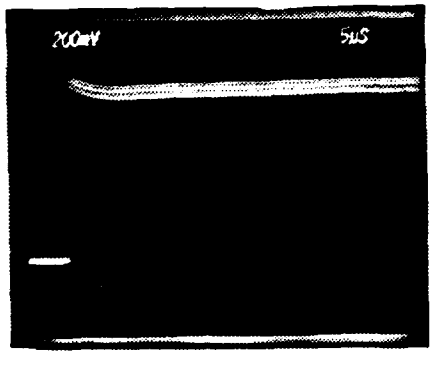
Vx = 600mV at 10V bias



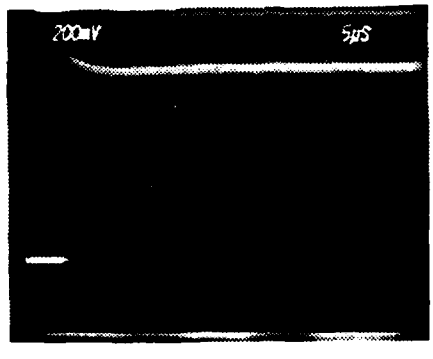
Vx = 680mV at 20V bias



Vx = 880mV at 30V bias

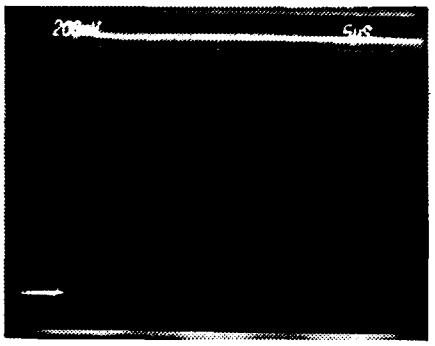


Vx = 980mV at 40V bias

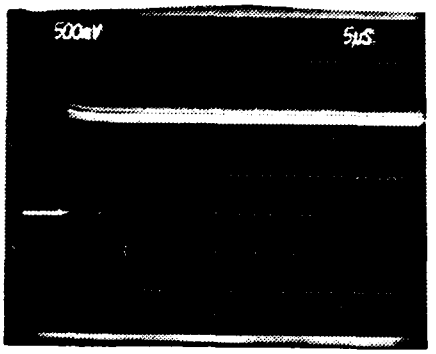


Vx = 1100mV at 50V bias

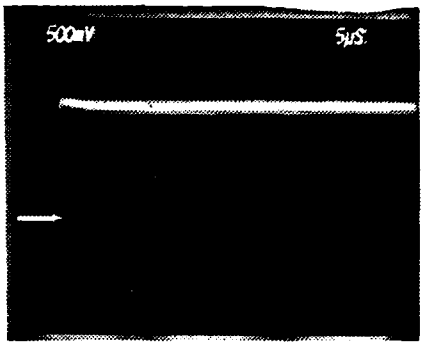
Figure A1.2. Photographs of sapphire irradiated with 30 MeV electrons



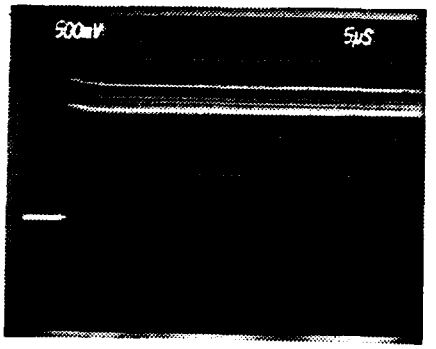
Vx = 1440mV at 60V bias



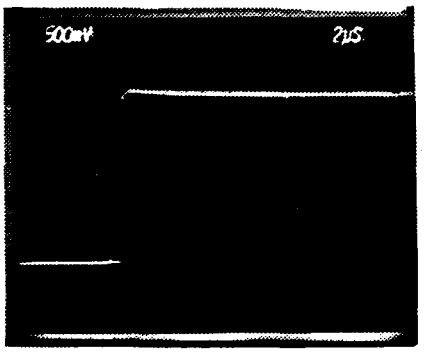
Vx = 1440mV at 70V bias



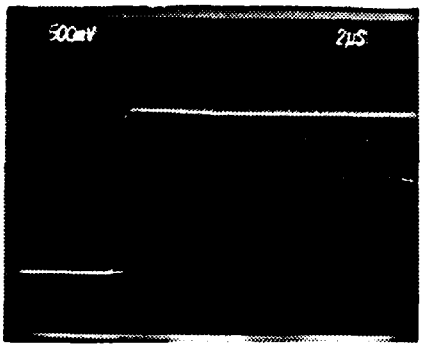
Vx = 1600mV at 80V bias



Vx = 1650mV at 100V bias

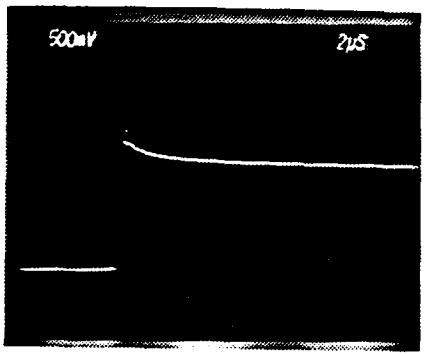


Vx = 2350mV at 150V bias

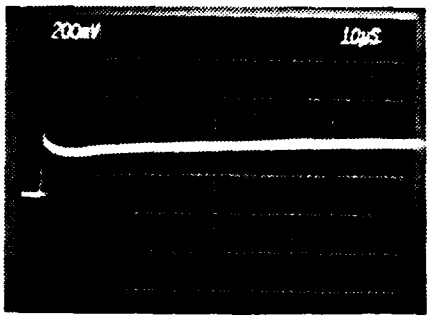


Vx = 2300mV at 175V bias

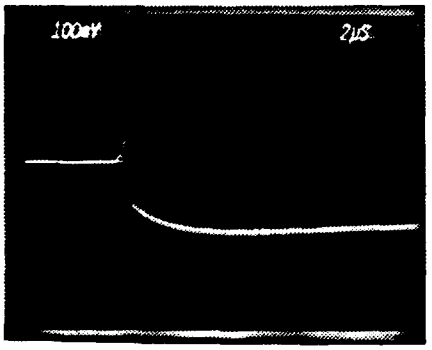
Figure A1.3. Photographs of sapphire irradiated with 30 MeV electrons. Positive bias voltages range from 60V to 175V.



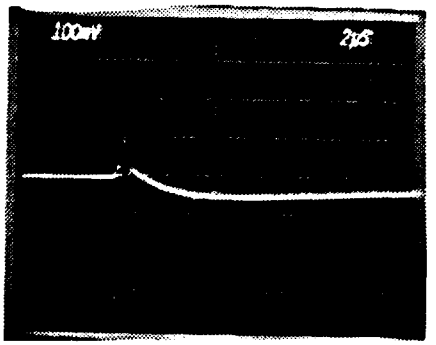
Vx = 1700 mV at 250V bias



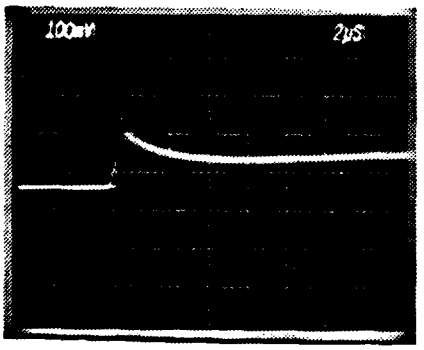
Vx = 320mV at OV bias



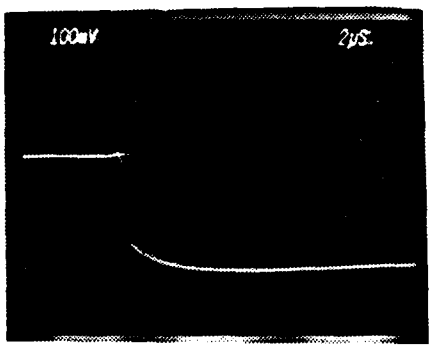
Vx = 140mV at -10V bias



Vx = 30mV at -20V bias

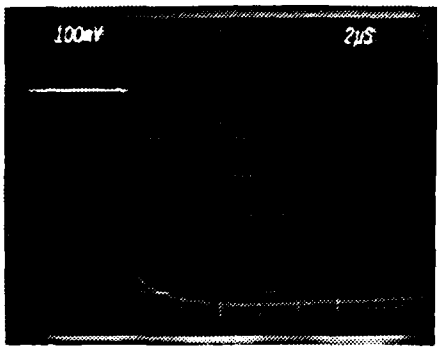


Vx = -100mV at -30V bias

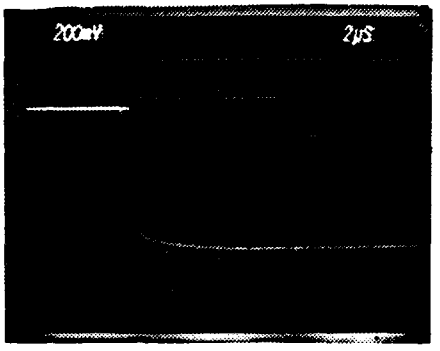


Vx = -115mV at -40V bias

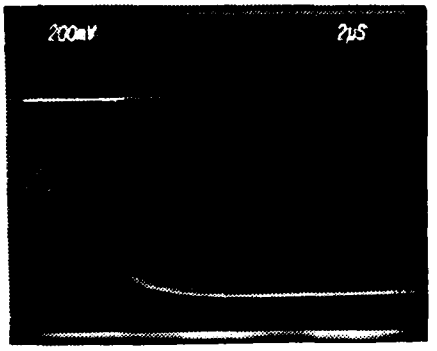
Figure A1.4. Photographs of sapphire irradiated with 30 MeV electrons. Bias voltages range from 250V to -40V.



Vx = -450mV at -60V Bias

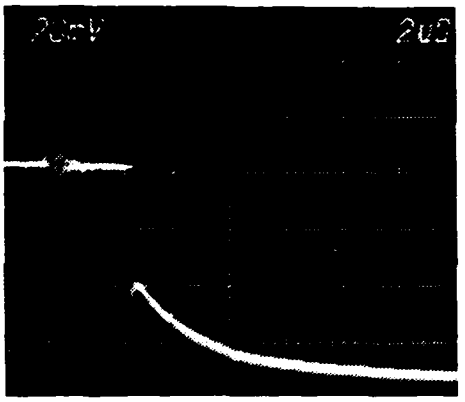


Vx = -680mV at -80V bias

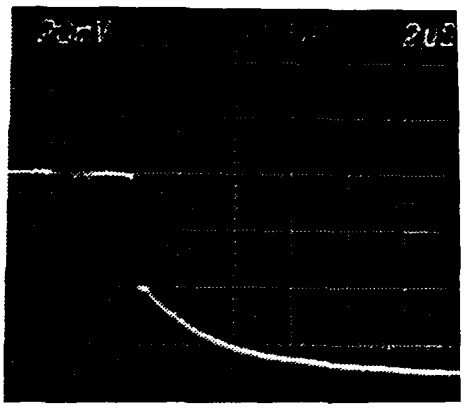


Vx = -920mV at -100V bias

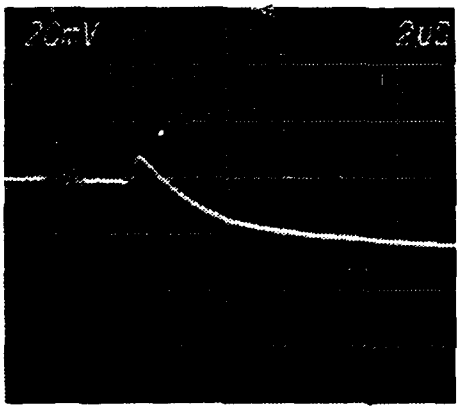
Figure A1.5. Photographs of sapphire irradiated with 30 MeV electrons. Negative bias voltages range from -60V to -100V.



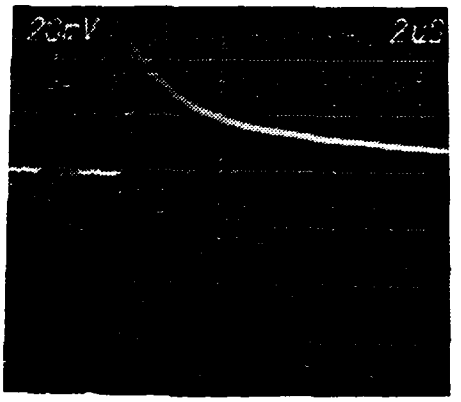
Vx = -40mV at OV bias



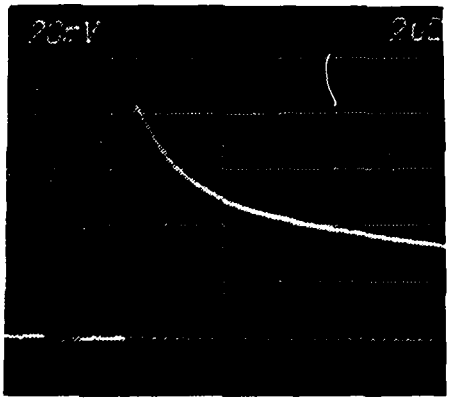
Vx = -40mV at 10V bias



Vx = 8mV at 20V bias



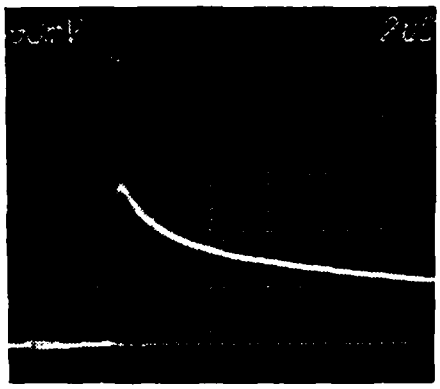
Vx = 44mV at 30V bias



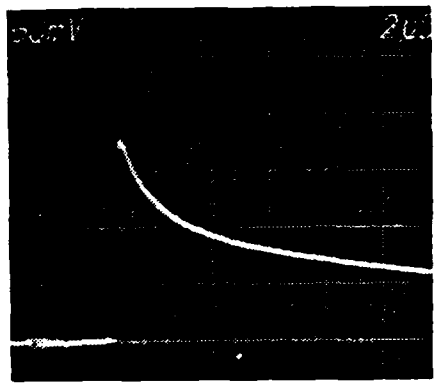
Vx = 84mV at 40V bias

Vx = 108mV at 50V bias

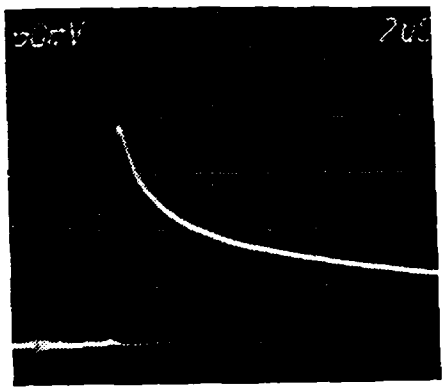
Figure A1.6. Alumina irradiated with 30 MeV electrons. Positive bias voltages range from OV to 50V.



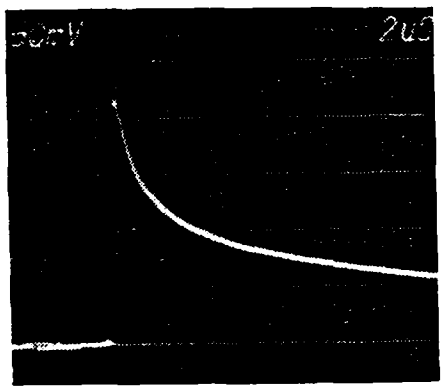
Vx = 140mV at 60V bias



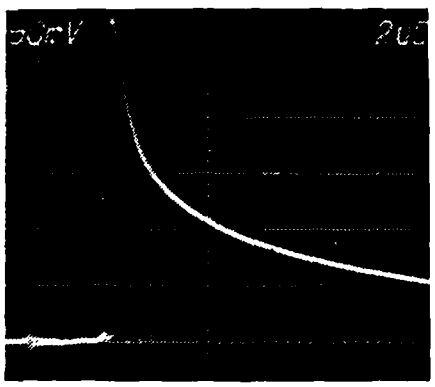
Vx = 180mV at 70V bias



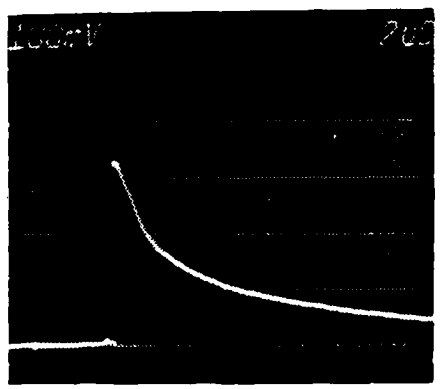
Vx = 195mV at 80V bias



Vx = 220mV at 100V bias

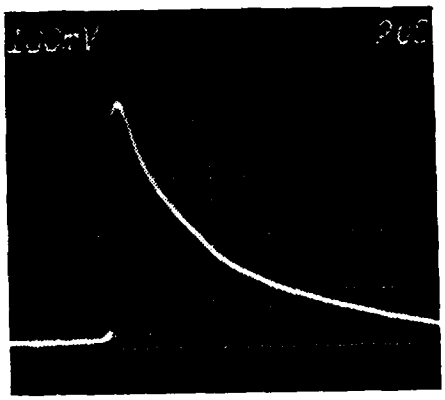


Vx = 290mV at 150V bias

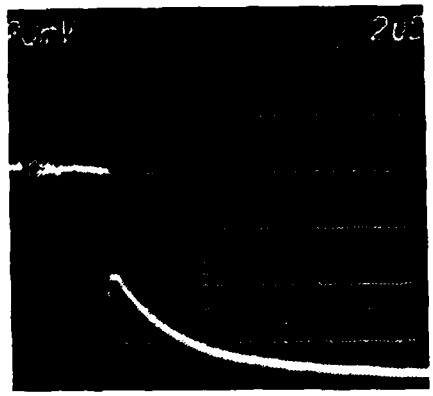


Vx = 340mV at 200V bias

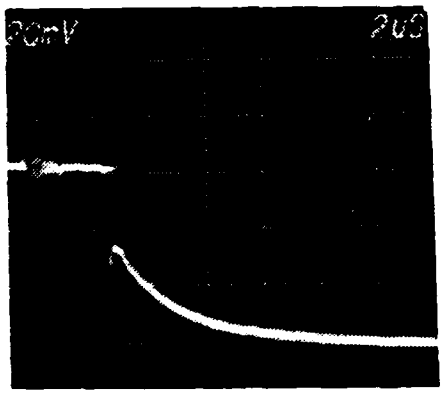
Figure A1.7. Alumina irradiated with 30MeV. Positive bias voltages ranging from 60V to 200V.



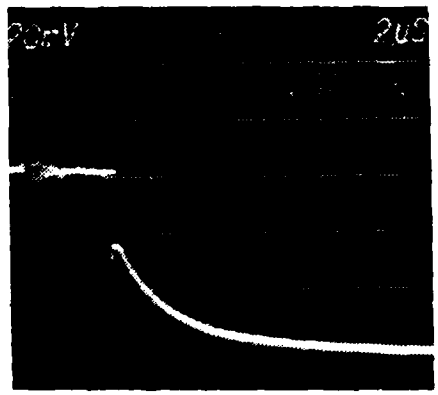
Vx = 440mV at 250V bias



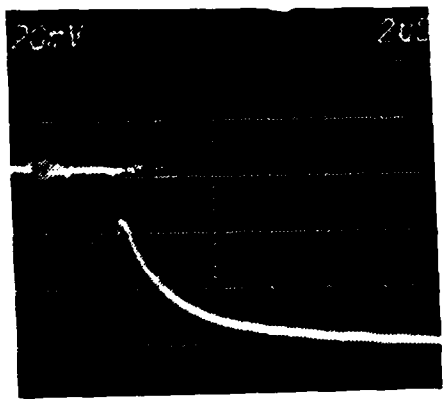
Vx = -40mV at 0V bias



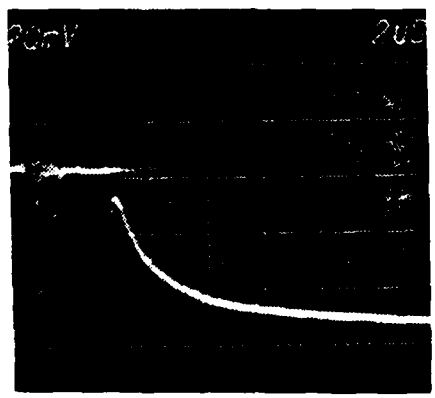
Vx = -24mV at -10V bias



Vx = -22mV at -20V bias

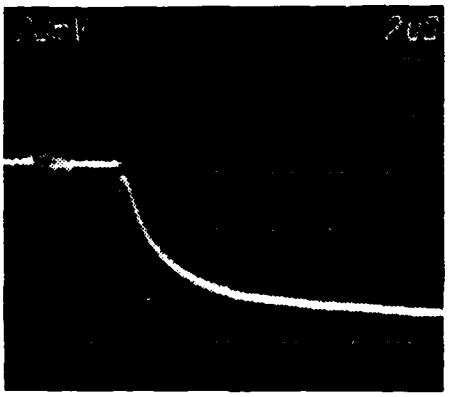


Vx = -15mV at -40V bias

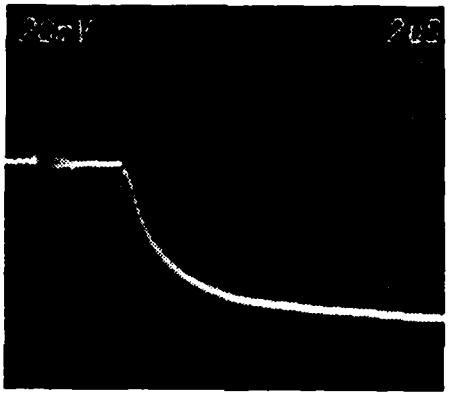


Vx = -6mV at -60V

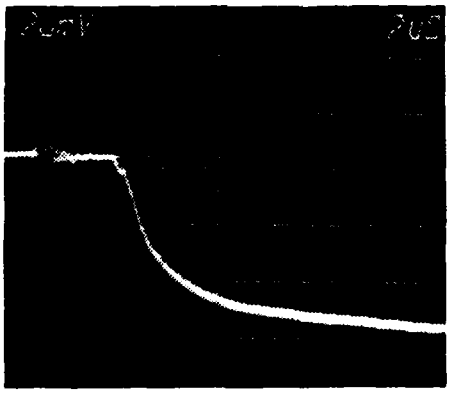
Figure A1.8. Alumina irradiated with 30 MeV electrons. Bias voltages range from 250V to -60V.



Vx = -4mV at -80V bias

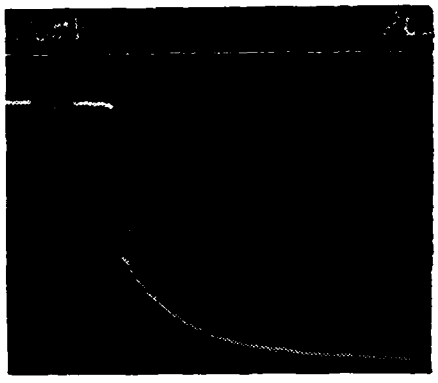


Vx = -2mV at -100V bias

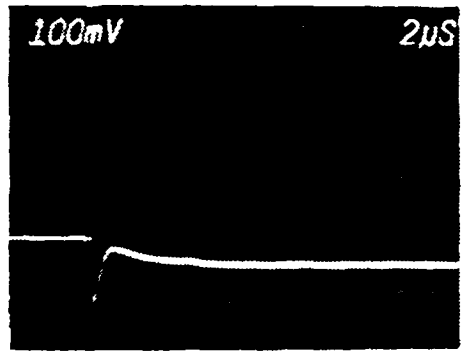


Vx = OmV at -110V bias

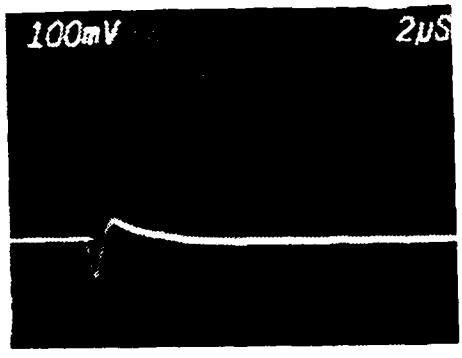
Figure A1.9. Alumina irradiated with 30 MeV electrons. Negative bias voltages range from -80V to-110V.



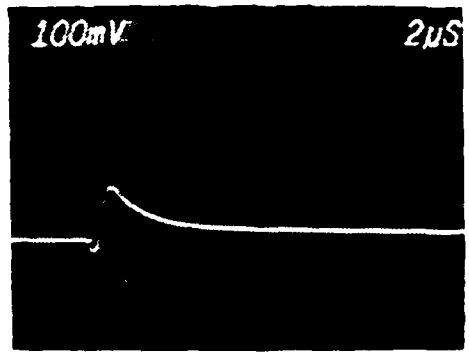
Vx = -52mV at OV bias



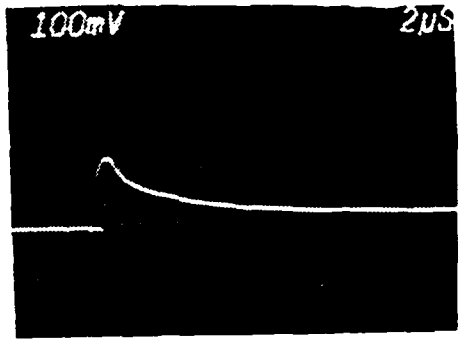
Vx = -20mV at 30V bias



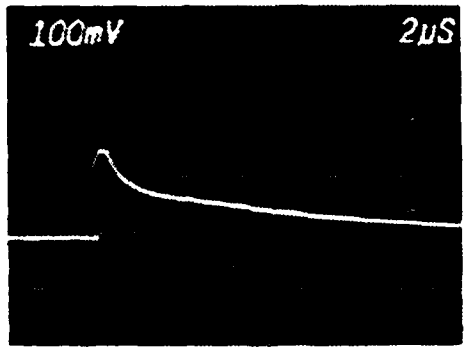
Vx = 40mV at 40V bias



Vx = 100mV at 60V bias

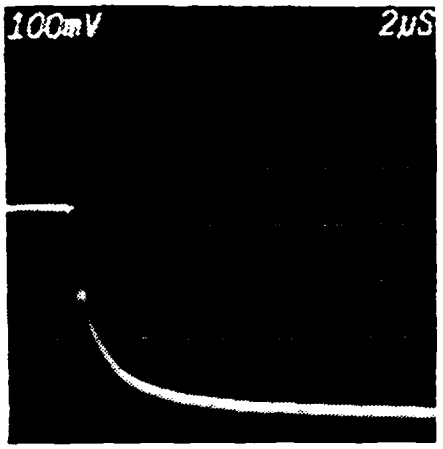


Vx = 130mV at 100V bias

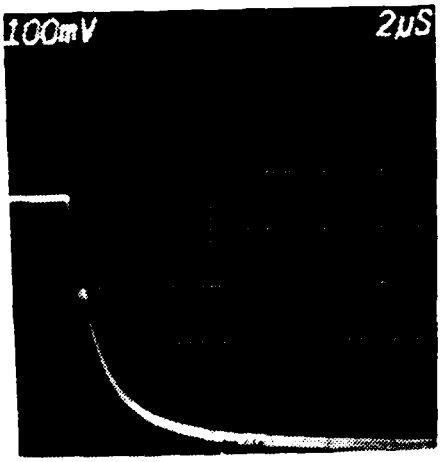


Vx = 160mV at 150V bias

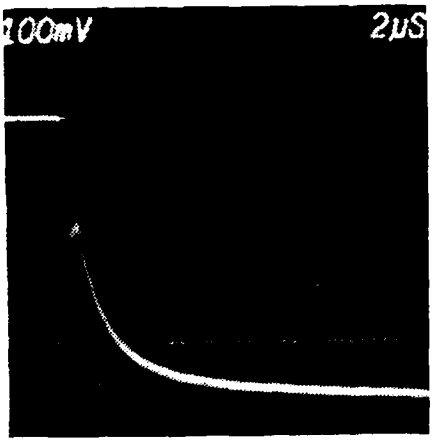
Figure A1.10. Alumina irradiated with 100 MeV electrons. Positive bias voltages range from OV to 150V.



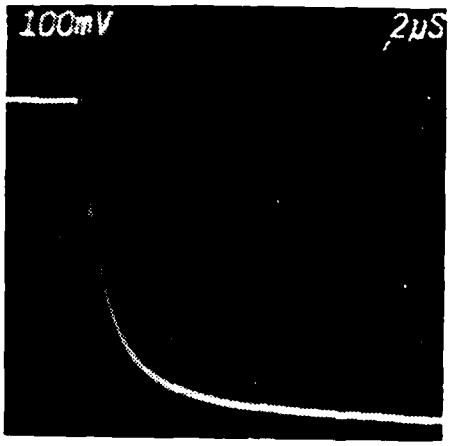
Vx = 210mV at 200V bias



Vx = 310mV at 250V bias

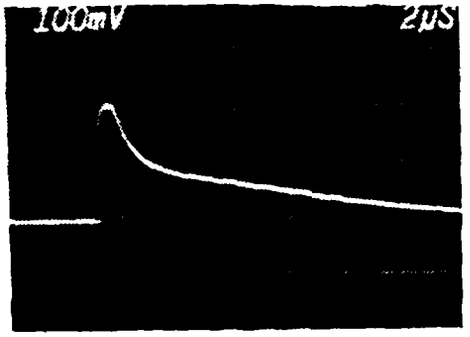


Vx = -220mV at OV bias

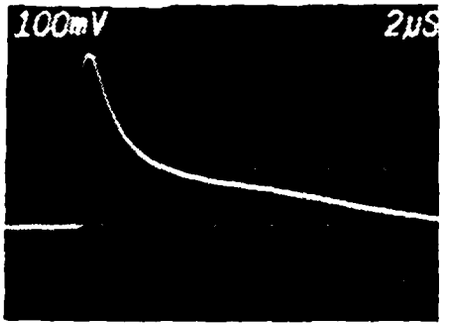


Vx = -160V at -30V bias

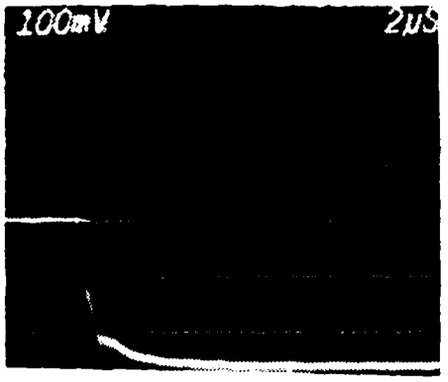
Figure A.1.11. Alumina irradiated with 100 MeV electrons. Bias voltage range from 250V to -30V.



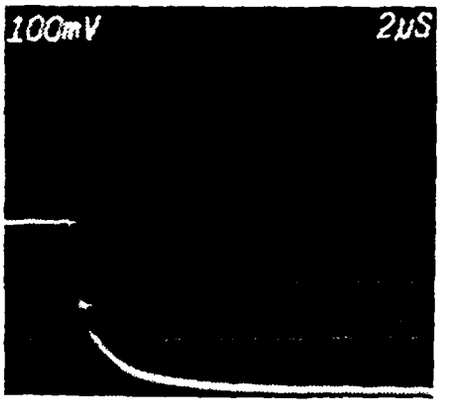
Vx = -150mV at -40V bias



Vx = -130mV at -60V bias



Vx = -180mV at -80V bias



Vx = -180mV at -100V bias

Figure A.1.12. Alumina irradiated with 100 MeV electrons. Negative bias voltages range from -40V to -100V.

APPENDIX B

TEST EQUIPMENT LIST:

1. Hewlett Packard 6209B DC Power Supply:
   0-320V, 0-.1A

2. Hewlett Packard 6205B Dual DC Power Supply:
   0-40V, .3A/0-20V, .6A

3. Hewlett Packard Harrison 6200B DC Power Supply:
   0-40V, .75A/0-20V, 1.5A

4. Keithley 617 Programmable Electrometer

5. Tektronix 7603 Oscilloscope
   7B85 delayed timing base, 7A26 dual trace

6. Tektronix 7904 Oscilloscope
   7B85 delayed timing base, 7A26 dual trace

7. Ohmite Ohm-Ranger
   resistance range 1 ohm thru 11,111,110 ohms

8. Weller Electronic Soldering Station

9. Tektronix C-5C Oscilloscope Camera

10. Tektronix C-51 Oscilloscope Camera

APPENDIX C

INPUT PROGRAM FOR ELECTRON PHOTON TRANSPORT ACCEPT CODE - CYLTRAN

To determine coupled electron/photon transport through a multimaterial target, CYLTRAN, a computer simulation code was used. CYLTRAN is part of the Integrated Tiger Series (ITS) of Coupled Electron/Photon Monte Carlo Transport codes. CYLTRAN was used on Cray computers, (at Los Alamos National Labratory) to simulate 30 MeV and 100 MeV electrons incident on an Al_2O_3 circular disk target. Enclosed is the Accept input program, the 30 MeV and 100 MeV cross sections, and Monte Carlo executions of 30 MeV and 100 Mev incident electrons.

```
1 ****************************************
  *                                      *
  *    PROGRAM XGEN - DECEMBER  1, 1984  *
  *             VERSION 1.0              *
  *                                      *
  ****************************************
  END OF FILE ON UNIT 5 - XGEN
          -------------------------
           SUMMARY OF INPUT DATA
          -------------------------
OMAXIMUM CROSS SECTION ENERGY =   3.0000e+01
OMATERIAL 1       SOLID/LIQUID
        DENSITY          3.9650e+00
        DENSITY-RATIO    1.0000e+00
       SYMBOL  ATOMIC NUMBER    WEIGHT FRACTION
 ------------------------------------------------
   1      O          8              4.7100e-01
   2      AL         13             5.2900e-01
O ************************************************************
  *                                                          *
  *  BEGIN EXECUTING PHOTON CROSS SECTION SUBROUTINE - PGEN  *
  *                                                          *
  ************************************************************
OEND OF PGEN SUBROUTINE
O************************************************************
 *                                                          *
 * BEGIN EXECUTING ELECTRON CROSS SECTION SUBROUTINE - DATPAC *
 *                                                          *
 ************************************************************


 30.0 MEV CROSS SECTIONS SAPPHIRE
1*********************************************
 *  ELECTRON CROSS SECTIONS FOR MATERIAL NUMBER  1  *
 *********************************************
O ITRM  IZIP  ISGN  ISUB  INEL  ICYC  NCYC  NMAX              EMAX
    5     0     1    40     1     1     8    64      3.00000e+01
OINPUT DATA TAPE IDENTIFICATION
 DATATAPE-2 (RESTER-AIGINGER PH-RAD CORR), 54 STERNHEIMER SETS. 30 JAN 6
ODETOUR          DENSITY
  1.31000e-01  3.96500e+00
O
ORANGE TABLE
O      EMAX        NCYC       EFAC        NMAX     T(NMAX+1)    NCAL      T(NCAL)
   3.00000e+01       8   9.17004e-01       64   1.17188e-01     120   9.98390e-04
O JMAX  LMAX
     2     1
O       Z             A             W
     8.00000      15.99939      0.47100
    13.00000      26.98148      0.52900
O       PI            PID
  121.89239     121.89239
O ------------------PARAMETERS FOR DENSITY EFFECT--------------------
       PI             C             A             DM            X1            X0

   121.89239     -3.22058      0.10475      3.00000      3.00000      0.20000
   121.89239     -3.22058      0.10478      3.00000      3.00000      0.20000
                                                    ELECTRON RESULTS
1  EFFECTIVE Z/A = 0.49039     EFFECTIVE MEAN IONIZATION POTENTIAL =  121.89 EV     CRITICAL ENERGY =   0.000 MEV
O       ENERGY          STOPPING POWER                RANGE    RADIATION   BETA**2   DENSITY   RAD/COL    DRANGE     DYIELD
O                                                                YIELD                  CORR
   N              COLLISION RADIATION   TOTAL                                        MEV CM2/G              G/CM2
          MEV     MEV CM2/G MEV CM2/G MEV CM2/G   G/CM2
```

120	9.9839e-04	8.718e+01	7.462e-03	8.719e+01	5.726e-06	0.000e+00	3.896e-03	0.000e+00	8.559e-05	5.726e-06	0.000e+00	
119	1.0868e-03	8.303e+01	7.457e-03	8.304e+01	6.788e-06	7.278e-06	4.248e-03	0.000e+00	8.981e-05	1.062e-06	7.924e-09	
118	1.1873e-03	7.898e+01	7.453e-03	7.898e+01	8.005e-06	1.432e-05	4.631e-03	0.000e+00	9.436e-05	1.217e-06	9.074e-09	
117	1.2948e-03	7.503e+01	7.447e-03	7.503e+01	9.402e-06	2.116e-05	5.049e-03	0.000e+00	9.926e-05	1.396e-06	1.040e-08	
116	1.4119e-03	7.119e+01	7.441e-03	7.120e+01	1.101e-05	2.786e-05	5.504e-03	0.000e+00	1.045e-04	1.604e-06	1.194e-08	
115	1.5397e-03	6.748e+01	7.434e-03	6.748e+01	1.285e-05	3.446e-05	5.999e-03	0.000e+00	1.102e-04	1.844e-06	1.372e-08	
114	1.6791e-03	6.389e+01	7.427e-03	6.390e+01	1.497e-05	4.100e-05	6.540e-03	0.000e+00	1.162e-04	2.123e-06	1.578e-08	
113	1.8311e-03	6.044e+01	7.419e-03	6.045e+01	1.742e-05	4.751e-05	7.129e-03	0.000e+00	1.228e-04	2.446e-06	1.816e-08	
112	1.9968e-03	5.713e+01	7.410e-03	5.713e+01	2.024e-05	5.404e-05	7.770e-03	0.000e+00	1.297e-04	2.821e-06	2.092e-08	
111	2.1775e-03	5.395e+01	7.401e-03	5.396e+01	2.350e-05	6.063e-05	8.469e-03	0.000e+00	1.372e-04	3.256e-06	2.412e-08	
110	2.3746e-03	5.091e+01	7.390e-03	5.092e+01	2.726e-05	6.732e-05	9.230e-03	0.000e+00	1.452e-04	3.762e-06	2.782e-08	
109	2.5895e-03	4.801e+01	7.379e-03	4.801e+01	3.161e-05	7.413e-05	1.006e-02	0.000e+00	1.537e-04	4.349e-06	3.212e-08	
108	2.8239e-03	4.524e+01	7.367e-03	4.525e+01	3.664e-05	8.112e-05	1.096e-02	0.000e+00	1.628e-04	5.031e-06	3.709e-08	
107	3.0795e-03	4.260e+01	7.353e-03	4.261e+01	4.246e-05	8.830e-05	1.195e-02	0.000e+00	1.726e-04	5.824e-06	4.286e-08	
106	3.3582e-03	4.010e+01	7.339e-03	4.010e+01	4.921e-05	9.573e-05	1.302e-02	0.000e+00	1.830e-04	6.746e-06	4.955e-08	
105	3.6621e-03	3.772e+01	7.323e-03	3.772e+01	5.703e-05	1.034e-04	1.418e-02	0.000e+00	1.941e-04	7.818e-06	5.731e-08	
104	3.9936e-03	3.546e+01	7.306e-03	3.547e+01	6.609e-05	1.115e-04	1.545e-02	0.000e+00	2.060e-04	9.066e-06	6.631e-08	
103	4.3550e-03	3.332e+01	7.288e-03	3.333e+01	7.661e-05	1.198e-04	1.683e-02	0.000e+00	2.187e-04	1.052e-05	7.675e-08	
102	4.7492e-03	3.130e+01	7.268e-03	3.131e+01	8.882e-05	1.285e-04	1.833e-02	0.000e+00	2.322e-04	1.221e-05	8.886e-08	
101	5.1790e-03	2.939e+01	7.248e-03	2.939e+01	1.030e-04	1.378e-04	1.997e-02	0.000e+00	2.466e-04	1.418e-05	1.029e-07	
100	5.6477e-03	2.758e+01	7.226e-03	2.759e+01	1.195e-04	1.475e-04	2.174e-02	0.000e+00	2.620e-04	1.647e-05	1.192e-07	
99	6.1589e-03	2.588e+01	7.203e-03	2.588e+01	1.386e-04	1.576e-04	2.368e-02	0.000e+00	2.784e-04	1.914e-05	1.381e-07	
98	6.7163e-03	2.427e+01	7.179e-03	2.428e+01	1.609e-04	1.684e-04	2.578e-02	0.000e+00	2.958e-04	2.225e-05	1.600e-07	
97	7.3242e-03	2.275e+01	7.154e-03	2.276e+01	1.867e-04	1.797e-04	2.806e-02	0.000e+00	3.144e-04	2.588e-05	1.854e-07	
96	7.9871e-03	2.133e+01	7.128e-03	2.133e+01	2.168e-04	1.917e-04	3.054e-02	0.000e+00	3.342e-04	3.010e-05	2.149e-07	
95	8.7100e-03	1.999e+01	7.102e-03	1.999e+01	2.519e-04	2.044e-04	3.324e-02	0.000e+00	3.553e-04	3.502e-05	2.492e-07	
94	9.4983e-03	1.873e+01	7.074e-03	1.873e+01	2.926e-04	2.179e-04	3.617e-02	0.000e+00	3.778e-04	4.076e-05	2.889e-07	
93	1.0358e-02	1.754e+01	7.046e-03	1.755e+01	3.401e-04	2.321e-04	3.934e-02	0.000e+00	4.017e-04	4.744e-05	3.350e-07	
92	1.1295e-02	1.643e+01	7.016e-03	1.644e+01	3.953e-04	2.472e-04	4.279e-02	0.000e+00	4.271e-04	5.523e-05	3.884e-07	
91	1.2318e-02	1.539e+01	6.989e-03	1.539e+01	4.596e-04	2.633e-04	4.652e-02	0.000e+00	4.542e-04	6.431e-05	4.504e-07	
90	1.3433e-02	1.441e+01	6.959e-03	1.441e+01	5.345e-04	2.803e-04	5.057e-02	0.000e+00	4.830e-04	7.489e-05	5.222e-07	
89	1.4648e-02	1.349e+01	6.930e-03	1.350e+01	6.217e-04	2.984e-04	5.496e-02	0.000e+00	5.136e-04	8.721e-05	6.056e-07	
88	1.5974e-02	1.263e+01	6.900e-03	1.264e+01	7.233e-04	3.176e-04	5.971e-02	0.000e+00	5.462e-04	1.016e-04	7.023e-07	
87	1.7420e-02	1.183e+01	6.871e-03	1.184e+01	8.416e-04	3.380e-04	6.485e-02	0.000e+00	5.809e-04	1.183e-04	8.145e-07	
86	1.8997e-02	1.108e+01	6.842e-03	1.108e+01	9.793e-04	3.596e-04	7.040e-02	0.000e+00	6.177e-04	1.378e-04	9.444e-07	
85	2.0716e-02	1.037e+01	6.814e-03	1.038e+01	1.140e-03	3.827e-04	7.641e-02	0.000e+00	6.569e-04	1.604e-04	1.095e-06	
84	2.2591e-02	9.715e+00	6.787e-03	9.722e+00	1.327e-03	4.071e-04	8.289e-02	0.000e+00	6.986e-04	1.868e-04	1.270e-06	
83	2.4636e-02	9.101e+00	6.760e-03	9.108e+00	1.544e-03	4.331e-04	8.988e-02	0.000e+00	7.428e-04	2.174e-04	1.473e-06	
82	2.6865e-02	8.528e+00	6.736e-03	8.534e+00	1.797e-03	4.607e-04	9.741e-02	0.000e+00	7.899e-04	2.531e-04	1.708e-06	
81	2.9297e-02	7.992e+00	6.713e-03	7.999e+00	2.091e-03	4.901e-04	1.055e-01	0.000e+00	8.399e-04	2.945e-04	1.980e-06	
80	3.1948e-02	7.493e+00	6.691e-03	7.500e+00	2.434e-03	5.213e-04	1.142e-01	0.000e+00	8.930e-04	3.426e-04	2.296e-06	
79	3.4840e-02	7.027e+00	6.672e-03	7.034e+00	2.832e-03	5.544e-04	1.238e-01	0.000e+00	9.494e-04	3.984e-04	2.662e-06	
78	3.7993e-02	6.593e+00	6.655e-03	6.600e+00	3.296e-03	5.896e-04	1.336e-01	0.000e+00	1.009e-03	4.631e-04	3.086e-06	
77	4.1432e-02	6.189e+00	6.640e-03	6.196e+00	3.834e-03	6.270e-04	1.444e-01	0.000e+00	1.073e-03	5.381e-04	3.577e-06	
76	4.5182e-02	5.813e+00	6.629e-03	5.819e+00	4.459e-03	6.667e-04	1.559e-01	0.000e+00	1.140e-03	6.249e-04	4.146e-06	
75	4.9271e-02	5.463e+00	6.621e-03	5.469e+00	5.184e-03	7.089e-04	1.682e-01	0.000e+00	1.212e-03	7.253e-04	4.805e-06	
74	5.3731e-02	5.137e+00	6.616e-03	5.144e+00	6.025e-03	7.537e-04	1.812e-01	0.000e+00	1.288e-03	8.413e-04	5.568e-06	
73	5.8594e-02	4.834e+00	6.616e-03	4.841e+00	7.000e-03	8.013e-04	1.952e-01	0.000e+00	1.369e-03	9.752e-04	6.452e-06	
72	6.3897e-02	4.553e+00	6.620e-03	4.560e+00	8.130e-03	8.517e-04	2.099e-01	0.000e+00	1.454e-03	1.130e-03	7.475e-06	
71	6.9680e-02	4.292e+00	6.630e-03	4.299e+00	9.437e-03	9.053e-04	2.256e-01	0.000e+00	1.545e-03	1.307e-03	8.659e-06	
70	7.5987e-02	4.050e+00	6.644e-03	4.056e+00	1.095e-02	9.622e-04	2.422e-01	0.000e+00	1.641e-03	1.511e-03	1.003e-05	
69	8.2864e-02	3.825e+00	6.665e-03	3.832e+00	1.269e-02	1.022e-03	2.596e-01	0.000e+00	1.742e-03	1.746e-03	1.162e-05	
68	9.0364e-02	3.617e+00	6.693e-03	3.624e+00	1.471e-02	1.086e-03	2.780e-01	0.000e+00	1.850e-03	2.014e-03	1.345e-05	
67	9.8543e-02	3.425e+00	6.728e-03	3.431e+00	1.703e-02	1.154e-03	2.972e-01	0.000e+00	1.965e-03	2.321e-03	1.557e-05	
66	1.0746e-01	3.246e+00	6.771e-03	3.253e+00	1.970e-02	1.226e-03	3.173e-01	0.000e+00	2.086e-03	2.671e-03	1.803e-05	
65	1.1719e-01	3.082e+00	6.825e-03	3.089e+00	2.277e-02	1.303e-03	3.383e-01	0.000e+00	2.215e-03	3.070e-03	2.087e-05	
64	1.2779e-01	2.930e+00	6.884e-03	2.937e+00	2.629e-02	1.384e-03	3.601e-01	0.000e+00	2.350e-03	3.524e-03	2.416e-05	
63	1.3936e-01	2.790e+00	6.959e-03	2.797e+00	3.033e-02	1.469e-03	3.827e-01	0.000e+00	2.495e-03	4.036e-03	2.795e-05	
62	1.5197e-01	2.661e+00	7.047e-03	2.668e+00	3.495e-02	1.560e-03	4.059e-01	0.000e+00	2.649e-03	4.621e-03	3.236e-05	
61	1.6573e-01	2.542e+00	7.149e-03	2.549e+00	4.023e-02	1.657e-03	4.298e-01	0.000e+00	2.812e-03	5.278e-03	3.746e-05	
60	1.8073e-01	2.433e+00	7.263e-03	2.440e+00	4.625e-02	1.759e-03	4.543e-01	0.000e+00	2.985e-03	6.018e-03	4.336e-05	
59	1.9709e-01	2.333e+00	7.398e-03	2.340e+00	5.310e-02	1.866e-03	4.792e-01	0.000e+00	3.171e-03	6.848e-03	5.020e-05	
58	2.1492e-01	2.242e+00	7.553e-03	2.249e+00	6.086e-02	1.983e-03	5.045e-01	0.000e+00	3.370e-03	7.779e-03	5.815e-05	

57	2.3438e-01	2.158e+00	7.731e-03	2.166e+00	6.969e-02	2.106e-03	5.300e-01	0.000e+00	3.582e-03	8.818e-03	6.738e-05
56	2.8559e-01	2.082e+00	7.924e-03	2.090e+00	7.967e-02	2.237e-03	5.557e-01	0.000e+00	3.806e-03	9.975e-03	7.807e-05
55	2.7872e-01	2.013e+00	8.154e-03	2.021e+00	9.093e-02	2.376e-03	5.813e-01	0.000e+00	4.050e-03	1.126e-02	9.051e-05
54	3.0395e-01	1.951e+00	8.415e-03	1.959e+00	1.036e-01	2.525e-03	6.068e-01	0.000e+00	4.314e-03	1.268e-02	1.051e-04
53	3.3146e-01	1.894e+00	8.706e-03	1.903e+00	1.179e-01	2.683e-03	6.321e-01	0.000e+00	4.596e-03	1.425e-02	1.220e-04
52	3.6146e-01	1.844e+00	9.040e-03	1.853e+00	1.338e-01	2.853e-03	6.570e-01	0.000e+00	4.903e-03	1.598e-02	1.418e-04
51	3.9417e-01	1.799e+00	9.417e-03	1.808e+00	1.517e-01	3.035e-03	6.813e-01	0.000e+00	5.236e-03	1.788e-02	1.650e-04
50	4.2985e-01	1.758e+00	9.842e-03	1.768e+00	1.717e-01	3.230e-03	7.050e-01	0.000e+00	5.597e-03	1.996e-02	1.922e-04
49	4.6875e-01	1.720e+00	1.032e-02	1.730e+00	1.939e-01	3.440e-03	7.280e-01	3.068e-03	6.002e-03	2.224e-02	2.242e-04
48	5.1118e-01	1.683e+00	1.087e-02	1.694e+00	2.187e-01	3.668e-03	7.501e-01	8.451e-03	6.455e-03	2.479e-02	2.626e-04
47	5.5744e-01	1.651e+00	1.148e-02	1.663e+00	2.463e-01	3.917e-03	7.713e-01	1.373e-02	6.952e-03	2.757e-02	3.081e-04
46	6.0789e-01	1.623e+00	1.217e-02	1.635e+00	2.769e-01	4.187e-03	7.914e-01	1.893e-02	7.498e-03	3.061e-02	3.619e-04
45	6.6291e-01	1.598e+00	1.295e-02	1.611e+00	3.108e-01	4.482e-03	8.105e-01	2.409e-02	8.100e-03	3.391e-02	4.258e-04
44	7.2291e-01	1.577e+00	1.382e-02	1.591e+00	3.483e-01	4.804e-03	8.285e-01	2.925e-02	8.765e-03	3.748e-02	5.017e-04
43	7.8834e-01	1.559e+00	1.481e-02	1.574e+00	3.896e-01	5.156e-03	8.453e-01	3.442e-02	9.498e-03	4.136e-02	5.920e-04
42	8.5969e-01	1.544e+00	1.591e-02	1.560e+00	4.352e-01	5.542e-03	8.610e-01	3.963e-02	1.031e-02	4.555e-02	6.995e-04
41	9.3750e-01	1.531e+00	1.715e-02	1.548e+00	4.853e-01	5.965e-03	8.756e-01	4.490e-02	1.120e-02	5.008e-02	8.277e-04
40	1.0224e+00	1.521e+00	1.854e-02	1.539e+00	5.402e-01	6.429e-03	8.889e-01	5.026e-02	1.219e-02	5.497e-02	9.807e-04
39	1.1149e+00	1.513e+00	2.010e-02	1.533e+00	6.005e-01	6.939e-03	9.012e-01	5.573e-02	1.328e-02	6.024e-02	1.164e-03
38	1.2158e+00	1.507e+00	2.185e-02	1.529e+00	6.664e-01	7.500e-03	9.124e-01	6.131e-02	1.450e-02	6.592e-02	1.382e-03
37	1.3258e+00	1.503e+00	2.383e-02	1.527e+00	7.384e-01	8.119e-03	9.226e-01	6.703e-02	1.586e-02	7.203e-02	1.645e-03
36	1.4458e+00	1.500e+00	2.603e-02	1.527e+00	8.171e-01	8.800e-03	9.318e-01	7.289e-02	1.735e-02	7.861e-02	1.960e-03
35	1.5767e+00	1.500e+00	2.849e-02	1.528e+00	9.027e-01	9.551e-03	9.401e-01	7.892e-02	1.900e-02	8.569e-02	2.336e-03
34	1.7194e+00	1.500e+00	3.124e-02	1.531e+00	9.960e-01	1.038e-02	9.475e-01	8.511e-02	2.083e-02	9.330e-02	2.786e-03
33	1.8750e+00	1.502e+00	3.433e-02	1.536e+00	1.098e+00	1.129e-02	9.541e-01	9.147e-02	2.286e-02	1.015e-01	3.327e-03
32	2.0447e+00	1.504e+00	3.778e-02	1.542e+00	1.208e+00	1.230e-02	9.600e-01	9.802e-02	2.510e-02	1.103e-01	3.974e-03
31	2.2298e+00	1.508e+00	4.159e-02	1.550e+00	1.327e+00	1.341e-02	9.652e-01	1.048e-01	2.758e-02	1.197e-01	4.749e-03
30	2.4316e+00	1.513e+00	4.585e-02	1.558e+00	1.457e+00	1.463e-02	9.698e-01	1.117e-01	3.031e-02	1.299e-01	5.676e-03
29	2.6517e+00	1.518e+00	5.064e-02	1.568e+00	1.598e+00	1.598e-02	9.739e-01	1.188e-01	3.336e-02	1.408e-01	6.792e-03
28	2.8916e+00	1.524e+00	5.593e-02	1.580e+00	1.751e+00	1.746e-02	9.774e-01	1.261e-01	3.671e-02	1.525e-01	8.123e-03
27	3.1534e+00	1.530e+00	6.182e-02	1.592e+00	1.916e+00	1.909e-02	9.806e-01	1.336e-01	4.040e-02	1.650e-01	9.714e-03
26	3.4388e+00	1.537e+00	6.840e-02	1.606e+00	2.094e+00	2.089e-02	9.833e-01	1.413e-01	4.450e-02	1.785e-01	1.162e-02
25	3.7500e+00	1.544e+00	7.569e-02	1.620e+00	2.287e+00	2.286e-02	9.856e-01	1.492e-01	4.901e-02	1.930e-01	1.390e-02
24	4.0894e+00	1.552e+00	8.378e-02	1.636e+00	2.496e+00	2.503e-02	9.877e-01	1.573e-01	5.398e-02	2.085e-01	1.662e-02
23	4.4595e+00	1.560e+00	9.277e-02	1.653e+00	2.721e+00	2.740e-02	9.894e-01	1.656e-01	5.946e-02	2.251e-01	1.986e-02
22	4.8631e+00	1.568e+00	1.027e-01	1.671e+00	2.964e+00	3.001e-02	9.910e-01	1.741e-01	6.550e-02	2.429e-01	2.373e-02
21	5.3033e+00	1.577e+00	1.138e-01	1.690e+00	3.225e+00	3.286e-02	9.923e-01	1.827e-01	7.216e-02	2.619e-01	2.834e+02
20	5.7833e+00	1.585e+00	1.260e-01	1.711e+00	3.508e+00	3.598e-02	9.934e-01	1.916e-01	7.950e-02	2.822e-01	3.383e-02
19	6.3067e+00	1.594e+00	1.396e-01	1.733e+00	3.812e+00	3.939e-02	9.944e-01	2.006e-01	8.757e-02	3.039e-01	4.035e-02
18	6.8776e+00	1.603e+00	1.546e-01	1.757e+00	4.139e+00	4.312e-02	9.952e-01	2.098e-01	9.646e-02	3.271e-01	4.809e-02
17	7.5000e+00	1.611e+00	1.712e-01	1.782e+00	4.490e+00	4.718e-02	9.959e-01	2.191e-01	1.063e-01	3.517e-01	5.728e-02
16	8.1788e+00	1.620e+00	1.896e-01	1.810e+00	4.868e+00	5.159e-02	9.965e-01	2.286e-01	1.170e-01	3.779e-01	6.816e-02
15	8.9191e+00	1.629e+00	2.098e-01	1.839e+00	5.274e+00	5.640e-02	9.971e-01	2.383e-01	1.288e-01	4.058e-01	8.102e-02
14	9.7263e+00	1.638e+00	2.323e-01	1.870e+00	5.709e+00	6.161e-02	9.975e-01	2.481e-01	1.418e-01	4 353e-01	9.621e-02
13	1.0607e+01	1.646e+00	2.570e-01	1.903e+00	6.176e+00	6.725e-02	9.979e-01	2.581e-01	1.561e-01	4.666e-01	1.141e-01
12	1.1567e+01	1.655e+00	2.843e-01	1.939e+00	6.676e+00	7.336e-02	9.982e-01	2.683e-01	1.718e-01	4.996e-01	1.352e-01
11	1.2613e+01	1.664e+00	3.145e-01	1.978e+00	7.210e+00	7.995e-02	9.985e-01	2.785e-01	1.890e-01	5.344e-01	1.600e-01
10	1.3755e+01	1.672e+00	3.477e-01	2.020e+00	7.781e+00	8.706e-02	9.987e-01	2.889e-01	2.079e-01	5.710e-01	1.890e-01
9	1.5000e+01	1.681e+00	3.843e-01	2.065e+00	8.390e+00	9.470e-02	9.989e-01	2.995e-01	2.286e-01	6.095e-01	2.230e-01
8	1.6358e+01	1.689e+00	4.247e-01	2.114e+00	9.040e+00	1.029e-01	9.991e-01	3.102e-01	2.514e-01	6.497e-01	2.627e-01
7	1.7838e+01	1.698e+00	4.691e-01	2.167e+00	9.732e+00	1.117e-01	9.992e-01	3.210e-01	2.763e-01	6.917e-01	3.090e-01
6	1.9453e+01	1.706e+00	5.180e-01	2.224e+00	1.047e+01	1.211e-01	9.993e-01	3.319e-01	3.036e-01	7.354e-01	3.628e-01
5	2.1213e+01	1.715e+00	5.717e-01	2.286e+00	1.125e+01	1.311e-01	9.994e-01	3.429e-01	3.335e-01	7.807e-01	4.253e-01
4	2.3133e+01	1.723e+00	6.309e-01	2.354e+00	1.208e+01	1.417e-01	9.995e-01	3.540e-01	3.662e-01	8.276e-01	4.975e-01
3	2.5227e+01	1.731e+00	6.960e-01	2.427e+00	1.295e+01	1.530e-01	9.996e-01	3.653e-01	4.021e-01	8.760e-01	5.810e-01
2	2.7510e+01	1.739e+00	7.674e-01	2.506e+00	1.388e+01	1.649e-01	9.997e-01	3.767e-01	4.413e-01	9.257e-01	6.771e-01
1	3.0000e+01	1.747e+00	8.459e-01	2.593e+00	1.485e+01	1.775e-01	9.997e-01	3.881e-01	4.843e-01	9.767e-01	7.876e-01

OEND OF DATPAC SUBROUTINE
OEND OF PROGRAM XGEN

```
                          PLANE          PLANE          RADIUS         RADIUS         CUTOFF      FORCING
  ZONE  MATERIAL          (CM)           (CM)           (CM)           (CM)           (MEV)       FRACTION
    1       1        0.00000e+00    2.97000e-03    0.00000e+00    9.52500e-01    1.500e+00    5.000e-01
1************************
 *  SOURCE INFORMATION  *
 ************************
OSOURCE ELECTRONS
OTHE MAXIMUM SOURCE ENERGY IS      30.00000 MEV
OTHE GLOBAL ELECTRON CUTOFF ENERGY IS       1.50000 MEV
OTHE PHOTON CUTOFF ENERGY IS       0.01000 MEV
OCOORDINATES OF THE POINT SOURCE OR OF THE CENTER OF THE BEAM (DISK) SOURCE ARE
     X =  0.00000e+00 CM          Y =  0.00000e+00 CM          Z =  0.00000e+00 CM
OTHE RADIUS OF THE BEAM (DISK) SOURCE IS =    0.0000e+00 CM
OREFERENCE DIRECTION FOR ANGULAR DISTRIBUTION IS DEFINED BY
      THETA =    0.0000 DEGREES          PHI =    0.0000 DEGREES
OMONODIRECTIONAL SOURCE IN REFERENCE DIRECTION
OTHE STANDARD ERROR ESTIMATES ARE BASED ON     10 BATCHES OF   100000 HISTORIES EACH
1********************
 *  OUTPUT OPTIONS  *
 ********************
OELECTRON-ESCAPE ENERGY CLASSIFICATIONS (MEV)
     27.00000     24.00000     21.00000     18.00000     15.00000     12.00000
      9.00000      6.00000      3.00000      1.50000
OELECTRON-ESCAPE POLAR ANGLE CLASSIFICATIONS (DEGREES)
     18.00000     36.00000     54.00000     72.00000     90.00000    108.00000
    126.00000    144.00000    162.00000    180.00000
OELECTRON-ESCAPE AZIMUTH ANGLE CLASSIFICATIONS (DEGREES)
    180.00000
OPHOTON-ESCAPE ENERGY CLASSIFICATIONS (MEV)
     27.00000     24.00000     21.00000     18.00000     15.00000     12.00000
      9.00000      6.00000      3.00000      0.01000
OPHOTON-ESCAPE POLAR ANGLE CLASSIFICATIONS (DEGREES)
     18.00000     36.00000     54.00000     72.00000     90.00000    108.00000
    126.00000    144.00000    162.00000    180.00000
OPHOTON-ESCAPE AZIMUTH ANGLE CLASSIFICATIONS (DEGREES)
    180.00000
OELECTRON-FLUX ENERGY CLASSIFICATIONS (MEV)
     27.00000     24.00000     21.00000     18.00000     15.00000     12.00000
      9.00000      6.00000      3.00000      1.50000
OPHOTON-FLUX ENERGY CLASSIFICATIONS (MEV)
     27.00000     24.00000     21.00000     18.00000     15.00000     12.00000
      9.00000      6.00000      3.00000      0.01000
1**********************
 *  PHYSICAL OPTIONS  *
 **********************
OELECTRON COLLISION AND RADIATION ENERGY LOSS STRAGGLING
OKNOCK-ON ELECTRON PRODUCTION
ONO COUPLED INELASTIC SCATTERING DEFLECTIONS
OBREMSSTRAHLUNG AND CHARACTERISTIC X-RAY QUANTA FOLLOWED
OBREMSSTRAHLUNG INTRINSIC ANGLE OF EMISSION FROM TABULATED DISTRIBUTION
OPHOTON-PRODUCED ELECTRONS FOLLOWED
O        MATERIAL NO.   1
 ELECTRON RANGE AT MAXIMUM SOURCE ENERGY IS       0.12774e+02 (G/CM**2)
 K X-RAY QUANTA FOLLOWED
 ELECTRON IMPACT IONIZATION SAMPLED
O        MATERIAL NO.   2
 ELECTRON RANGE AT MAXIMUM SOURCE ENERGY IS       0.13516e+02 (G/CM**2)
 K X-RAY QUANTA FOLLOWED
 ELECTRON IMPACT IONIZATION SAMPLED
OANNIHILATION QUANTA FOLLOWED
O THE VOLUME RATIO IS       0.1000000000000e+01
1*******************************************************************************
 *                                                                             *
 * ...30.0 MEV TEST PROGRAM                                                    *
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 *                                                                              *
 ********************************************************************************
OTHE PROBLEM IS  100  PERCENT COMPLETE.  TIME TO FINISH IS        0.000 SECONDS. AVERAGE TIME PER BATCH IS        11.232
OAVERAGE SOURCE ENERGY = 3.0000e+01  0 MEV
OTHE INITIAL RANDOM NUMBER OF THIS RUN IS 000000000000000000
 THE INITIAL RANDOM NUMBER OF THE CURRENT BATCH IS 000063542336250032S5
 THE  FINAL  RANDOM NUMBER OF THE CURRENT BATCH IS 000011140474272761 31
O    ------------------------------------ HISTORIES ------------------------------------        REJ      REJ        --- STEPS ----
     PRIM       SEC     KNOCK       P E      PAIR       COM     AUGER      BREM       RAD      XRAY      LAND     PEAL       PRIM       SEC
  1000000      2795       612        20      1317       846         0     11623     11627      5176         0        3    1000000      2796
O                        ENERGY (MEV)       AVE ENERGY (MEV)       NUMBER/PRIMARY       NUMBER GENERATED
 FIRST KNOCK (ABOVE TCUT)      2.4223e-03          3.9645e+00           6.1100e-04                611
 TOTAL KNOCK (ABOVE TCUT)      2.4223e-03          3.9645e+00           6.1100e-04                612
 PHOTO-ELECTRON                1.9167e-05          2.4799e-02           7.7290e-04               5202
 PAIR                          5.0063e-06          5.7693e+00           8.6774e-07               1720
 COMPTON                       2.6490e-06          1.6707e-01           1.5855e-05               4549
 AUGER                         1.7900e-05          2.4710e-02           7.2442e-04               1074
 FIRST BREMSSTRAHLUNG          3.5279e-02          3.0382e+00           1.1612e-02              11612
 TOTAL BREMSSTRAHLUNG          3.5279e-02          3.0374e+00           1.1615e-02              11627
 K X-RAY(P-IONIZATION)         2.3374e-06          2.4710e-02           9.4593e-05               1800
 K X-RAY(E-IONIZATION)         8.3396e-05          2.4710e-02           3.3750e-03               3376
 ANNIHILATION QUANTA           8.9598e-10          5.1098e-01           1.7535e-09                  2

1UNSCATTERED PRIMARY PHOTONS -- NUMBER AND ENERGY FRACTIONS
 0.00e+00 99 0.00e+00 99
  ***UNSCATTERED PRIMARY PHOTONS ARE EXCLUDED FROM ALL SUBSEQUENT PHOTON ESCAPE TALLIES***
ONUMBER ESCAPE FRACTIONS --- KNOCK-ON AND PHOTON GENERATED ELECTRONS, ANNIHILATION RADIATION, K-X-RAYS (MATERIAL NO.)
O                                        TRANSMISSION
        KNOCK          P-SEC          ANNIH     K-X-RAY(1)     K-X-RAY(2)     K-X-RAY(3)     K-X-RAY(4)     K-X-RAY(5)
   6.05e-04  5   1.07e-06  4   8.76e-10 99   1.38e-03  2   0.00e+00 99
O                                        REFLECTION
        KNOCK          P-SEC          ANNIH     K-X-RAY(1)     K-X-RAY(2)     K-X-RAY(3)     K-X-RAY(4)     K-X-RAY(5)
   0.00e+00 99   9.64e-09 49   8.76e-10 99   1.45e-03  2   0.00e+00 99
O                                        LATERAL ESCAPE
        KNOCK          P-SEC          ANNIH     K-X-RAY(1)     K-X-RAY(2)     K-X-RAY(3)     K-X-RAY(4)     K-X-RAY(5)
   0.00e+00 99   0.00e+00 99   0.00e+00 99   1.34e-23 29   0.00e+00 99

O                                  NUMBER AND ENERGY ESCAPE FRACTIONS
O                                        TRANSMISSION
O                          ---------- ELECTRON ----------          ---------- PHOTON ----------
                             NUMBER      ENERGY      COUNTS       NUMBER      ENERGY      COUNTS

                         1.00e+00  0 9.98e-01  0    1002748  1.28e-02  1 1.18e-03  2       17307
O                                        REFLECTION
O                          ---------- ELECTRON ----------          ---------- PHOTON ----------
                             NUMBER      ENERGY      COUNTS       NUMBER      ENERGY      COUNTS

                         9.64e-09 49 2.22e-09 63         14  1.46e-03  2 1.24e-06  1        4024
O                                        LATERAL ESCAPE
O                          ---------- ELECTRON ----------          ---------- PHOTON ----------
                             NUMBER      ENERGY      COUNTS       NUMBER      ENERGY      COUNTS

                         0.00e+00 99 0.00e+00 99          0  2.40e-09 48 2.80e-11 49         19
1                                      ENERGY DEPOSITION
                                  (NORMALIZED TO ONE INCIDENT PARTICLE)
O                                                                          ENERGY DEPOSITION (MEV)
     ZONE       MATERIAL      MASS(GM)   VOLUME(CC)                              PRIM          KNOCK          G-SEC          TOTAL
       1              1   4.0464e-02     8.4652e-03                      1.9862e-02  0 -2.4159e-03  4 -7.0450e-05  2  1.7376e-02  1
O                                                                TOTAL     1.9862e-02  0 -2.4159e-03  4 -7.0450e-05  2  1.7376e-02  1
O THE ENERGY CONSERVATION FRACTION IS       0.1000118596388e+01  0
1                                      CHARGE DEPOSITION
                                  (NORMALIZED TO ONE INCIDENT PARTICLE)
O                                                                          ELECTRONS
     ZONE      MATERIAL     ZL          ZR          RI          RO              PRIM          KNOCK          G-SEC          TOTAL
```

AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

E (MEV)			THETA= 162.000 180.000
30.0000	- 27.0000	0.00e+00	99
27.0000	- 24.0000	0.00e+00	99
24.0000	- 21.0000	0.00e+00	99
21.0000	- 18.0000	0.00e+00	99
18.0000	- 15.0000	0.00e+00	99
15.0000	- 12.0000	0.00e+00	99
12.0000	- 9.0000	0.00e+00	99
9.0000	- 6.0000	0.00e+00	99
6.0000	- 3.0000	0.00e+00	99
3.0000	- 1.5000	0.00e+00	99

ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF ELECTRONS LATERALLY ESCAPING
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

E (MEV)		THETA= 0.000 18.000	18.000 36.000	36.000 54.000	54.000 72.000	72.000 90.000	90.000 108.000	108.000 126.000	126.000 144.000	144.000 162.000
30.0000 - 27.0000		0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
27.0000 - 24.0000		0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
24.0000 - 21.0000		0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
21.0000 - 18.0000		0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
18.0000 - 15.0000		0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
15.0000 - 12.0000		0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
12.0000 - 9.0000		0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
9.0000 - 6.0000		0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
6.0000 - 3.0000		0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
3.0000 - 1.5000		0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99

ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF ELECTRONS LATERALLY ESCAPING
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

E (MEV)			THETA= 162.000 180.000
30.0000 -	27.0000	0.00e+00	99
27.0000 -	24.0000	0.00e+00	99
24.0000 -	21.0000	0.00e+00	99
21.0000 -	18.0000	0.00e+00	99
18.0000 -	15.0000	0.00e+00	99
15.0000 -	12.0000	0.00e+00	99
12.0000 -	9.0000	0.00e+00	99
9.0000 -	6.0000	0.00e+00	99
6.0000 -	3.0000	0.00e+00	99
3.0000 -	1.5000	0.00e+00	99

ENERGY SPECTRA OF TRANSMITTED PHOTONS
(NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)

E (MEV)			
30.0000 -	27.0000	1.53e-05	15
27.0000 -	24.0000	3.10e-05	7
24.0000 -	21.0000	4.43e-05	10
21.0000 -	18.0000	5.03e-05	7
18.0000 -	15.0000	7.33e-05	9
15.0000 -	12.0000	9.00e-05	5
12.0000 -	9.0000	1.24e-04	5
9.0000 -	6.0000	1.92e-04	3
6.0000 -	3.0000	3.67e-04	3
3.0000 -	0.0100	3.31e-03	1

ENERGY SPECTRA OF REFLECTED PHOTONS
(NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)

E (MEV)				
30.0000	-	27.0000	0.00e+00	99
27.0000	-	24.0000	0.00e+00	99
24.0000	-	21.0000	0.00e+00	99
21.0000	-	18.0000	0.00e+00	99
18.0000	-	15.0000	0.00e+00	99
15.0000	-	12.0000	0.00e+00	99
12.0000	-	9.0000	0.00e+00	99
9.0000	-	6.0000	0.00e+00	99
6.0000	-	3.0000	0.00e+00	99
3.0000	-	0.0100	4.87e-04	2

ENERGY SPECTRA OF LATERALLY ESCAPING PHOTONS
(NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)

E (MEV)				
30.0000	-	27.0000	0.00e+00	99
27.0000	-	24.0000	0.00e+00	99
24.0000	-	21.0000	0.00e+00	99
21.0000	-	18.0000	0.00e+00	99
18.0000	-	15.0000	0.00e+00	99
15.0000	-	12.0000	0.00e+00	99
12.0000	-	9.0000	0.00e+00	99
9.0000	-	6.0000	0.00e+00	99
6.0000	-	3.0000	0.00e+00	99
3.0000	-	0.0100	8.02e-10	48

ANGULAR DISTRIBUTIONS OF TRANSMITTED AND REFLECTED PHOTON INTENSITY
(MEV/SR, NORMALIZED TO ONE INCIDENT PARTICLE)

THETA (DEG)			PHI(DEG)= 0.000	180.000
0.0000	-	18.0000	1.14e-01	2
18.0000	-	36.0000	1.56e-04	24
36.0000	-	54.0000	2.74e-05	59
54.0000	-	72.0000	6.21e-06	7
72.0000	-	90.0000	5.31e-06	24
90.0000	-	108.0000	4.39e-06	5
108.0000	-	126.0000	6.53e-06	4
126.0000	-	144.0000	6.14e-06	5
144.0000	-	162.0000	7.29e-06	8
162.0000	-	180.0000	6.88e-06	6

ANGULAR DISTRIBUTIONS OF LATERALLY ESCAPING PHOTON INTENSITY
(MEV/SR, NORMALIZED TO ONE INCIDENT PARTICLE)

THETA (DEG)			PHI(DEG)= 0.000	180.000
0.0000	-	18.0000	0.00e+00	99
18.0000	-	36.0000	0.00e+00	99
36.0000	-	54.0000	0.00e+00	99
54.0000	-	72.0000	0.00e+00	99
72.0000	-	90.0000	1.19e-10	75
90.0000	-	108.0000	3.14e-10	68
108.0000	-	126.0000	0.00e+00	99
126.0000	-	144.0000	0.00e+00	99
144.0000	-	162.0000	0.00e+00	99
162.0000	-	180.0000	0.00e+00	99

```
    0.000050    0.000036
    0.000049    0.000044
    0.000127    0.000099
ORATIO OF SCATTERING TO SCATTERING PLUS PAIR PRODUCTION ATTENUATION COEFFICIENTS
    0.003562    0.004484    0.006042    0.007307    0.009231    0.012506
    0.019266    0.026255    0.040730    0.052435    0.071847    0.087451
    0.111168    0.151439    0.230586    0.302629    0.428773    0.511521
    0.627310    0.701006    0.785222    0.875673    0.959669    0.990910
    1.000000
OK SHELL IONIZATION DATA
OBINDING ENERGY (MEV), PHOTOEFFECT EFFICIENCY AND FLUORESCENT EFFICIENCY
    0.011867    0.476827    0.520756
OK X-RAY ENERGIES (MEV)
    0.010690    0.010690    0.010690    0.010690
OK X-RAY ACCUMULATED RELATIVE INTENSITIES
    1.000000    1.000000    1.000000    1.000000
OAUGER ELECTRON ENERGIES (MEV)
    0.010690    0.010690    0.010690
OAUGER ELECTRON ACCUMULATED RELATIVE INTENSITIES
    1.000000    1.000000    1.000000
1*********************************************************
 *    ELECTRON CROSS SECTION DATA FROM PROGRAM DATPAC     *
 *********************************************************
ONUMBER OF SETS ON DATAPAC TAPE =   2
O********************100.0 MEV CROSS SECTIONS FOR PHOTOCONDUCTORS                    ********************

OMATERIAL       DENSITY       DETOUR
        1  0.47800e+01  0.73100e+00
              Z             A             W
  0.15000e+02  0.30974e+02  0.21200e+00
  0.49000e+02  0.11482e+03  0.78800e+00
  NSET  ITRM  IZIP  ISGN  ISUB  INAL  ICYC  NCYC  NMAX      EMAX           EMIN           RMAX          LMAT
     1     5     0     1    40     1     1     8    64  1.0000000e+02  3.9062500e-01  2.3175160e+01     2
  DATAPREP DATA FOR DATAPAC SET   1    64    33    40   121  2.317516e+01


OMATERIAL       DENSITY       DETOUR
        2  0.53200e+01  0.39500e+00
              Z             A             W
  0.31000e+02  0.69720e+02  0.48200e+00
  0.33000e+02  0.74922e+02  0.51800e+00
  NSET  ITRM  IZIP  ISGN  ISUB  INAL  ICYC  NCYC  NMAX      EMAX           EMIN           RMAX          LMAT
     2     5     0     1    40     1     1     8    64  1.0000000e+02  3.9062500e-01  2.5400030e+01     2
  DATAPREP DATA FOR DATAPAC SET   2    64    33    40   121  2.540003e+01

O COLLISION / TOTAL DE/DX RATIOS FOR DATAPAC SET   2
O CUMULATIVE BREMSSTRAHLUNG CROSS SECTIONS FOR DATAPAC SET   2
O CUMULATIVE BREMSSTRAHLUNG ANGULAR DISTRIBUTIONS FOR DATAPAC SET   2
O LANGAUSS - EQUIPROBABLE ENDPOINTS FOR INTERPOLATION
O K X-RAY PRODUCTION FOR DATAPAC SET   2
O PHOTOELECTRON ANGULAR DISTRIBUTIONS
O PAIR ELECTRON ENERGY DIVISION DISTRIBUTION (LEAD)
1*************************
 *   BEGIN READING INPUT   *
 *************************
 TITLE
 ...30.0 MEV TEST PROGRAM
 ************************SOURCE************************
 ELECTRONS
 ENERGY 30.0
 * DEFAULT SOURCE PHASE SPACE PARAMETERS
 * POSITION 0.0 0.0 0.0
 SOURCE-RADIUS 0.9525O
O WARNING. ILLEGAL COMMAND LINE - INFORMATION IGNORED
```

```
 -->SOURCE-RADIUS 0.95250
 * MONODIRECTIONAL Z-AXIS
 ************************OTHER OPTIONS*****************
 HISTORIES 1000000
 BATCHES 10
 CUTOFF 0.05 .001
0 WARNING. ILLEGAL COMMAND LINE - INFORMATION IGNORED
 -->CUTOFF 0.05 .001
 ************************OUTPUT OPTIONS****************
 ELECTRON-ESCAPE
 NBINE 10
 NBINT 10
 PHOTON-ESCAPE
 NBINE 10
 NBINT 10
 ELECTRON-FLUX 1 1
 NBINE 10
 PHOTON-FLUX 1 1
 NBINE 10
 ************************GEOMETRY**********************
 GEOMETRY 1
  *ZL       ZR       RI       RO MAT   IZR   NZ    NR  ECUT  PTCZ
 0.0 0.00297 0.0 0.95250 1 1 1 1 0.0 0.5
0 EOF ON UNIT  5 BEGIN PROCESSING - INPUT
1*********************************************************
 *   COMPARISON OF STORAGE REQUIREMENTS VS ALLOCATIONS   *
 *********************************************************
ONUMBER OF MATERIALS ON CROSS SECTION FILE                                / INMT  =    2 /     5
 LENGTH OF ELECTRON CROSS SECTION ENERGY GRID                             / INMAX =   64 /    64
 ELECTRON ENERGY GRID LENGTH FOR SAMPLING BREMS. PHOTON ENERGY            / IMTOP =   65 /    65
 PHOTON ENERGY GRID LENGTH FOR SAMPLING BREMS. PHOTON ENERGY              / IKTOP =   49 /    49
 ELECTRON ANGLE GRID LENGTH FOR SAMPLING ELECTRON SCATTERING ANGLE        / IMMAX =   33 /    33
 PHOTON ANGLE GRID LENGTH FOR SAMPLING BREMS. PHOTON ANGLE                / INPANG =  21 /    21
 PHOTON ENERGY GRID LENGTH FOR SAMPLING BREMS. PHOTON ANGLE               / INRANG =  25 /    25
 ELECTRON ENERGY GRID LENGTH FOR SAMPLING BREMS. PHOTON ANGLE             / INTANG =   9 /     9
 PHOTON ENERGY GRID LENGTH FOR SAMPLING PHOTO-ELECTRON DIRECTION          / INEEL =   13 /    17
 ELECTRON ANGLE GRID LENGTH FOR SAMPLING PHOTO-ELECTRON DIRECTION         / INPEL =   21 /    21
 PHOTON ENERGY GRID LENGTH FOR SAMPLING PAIR ELECTRON ENERGY              / INEPS =    9 /    17
 ELECTRON ENERGY GRID LENGTH FOR SAMPLING PAIR ELECTON ENERGY             / INPPS =   21 /    21
 GAUSSIAN FUNCTION GRID FOR SAMPLING ELECTRON ENERGY LOSS STRAGGLING      / INGAS =  100 /   100
 LANDAU FUNCTION GRID FOR SAMPLING ELECTRON ENERGY LOSS STRAGGLING        / INLAN =  500 /   500
 MAXIMUM NUMBER OF TABLES OF PHOTON CROSS SECTIONS                        / INTAB =    9 /    15
 MAXIMUM LENGTH OF PHOTON CROSS SECTION TABLE                             / IMTAX =   41 /    48
 NUMBER OF ELECTRON ESCAPE ENERGY BINS                                    / IJMAX =   10 /    50
 NUMBER OF PHOTON ESCAPE ENERGY BINS                                      / IJPMAX =  10 /    50
 NUMBER OF ELECTRON ESCAPE POLAR ANGLE BINS                               / IKMAX =   10 /    36
 NUMBER OF PHOTON ESCAPE POLAR ANGLE BINS                                 / IKPMAX =  10 /    36
 LENGTH OF SOURCE SPECTRUM ENERGY GRID                                    / IJSPEC =   0 /    51
 NUMBER OF PULSE HEIGHT ENERGY BINS                                       / IJSMAX =   0 /    53
 NUMBER OF ELECTRON FLUX ENERGY BINS                                      / IJFMAX =  10 /    50
 NUMBER OF PHOTON FLUX ENERGY BINS                                        / IJFMXP =  10 /    50
 NUMBER OF ELECTRON FLUX ZONES                                            / INLF  =    1 /    10
 NUMBER OF PHOTON FLUX ZONES                                              / INLFP =    1 /    10
 NUMBER OF PROBLEM ZONES                                                  / INZON =    1 /   100
 SIZE OF DOUBLY DIFFERENTIAL BREMS DISTRIBUTION                           / NCHANG = 4725 /  4725
 SIZE OF SINGLY DIFFERENTIAL BREMS DISTRIBUTION                           / NBDIS = 3185 /  3185
 SIZE OF GOUDSMIT-SAUNDERSON ANGULAR DISTRIBUTION                         / NGG   = 2112 /  2112
 NO. OF ELECTRON ESCAPE AZIMUTHAL ANGLE BINS                              / IKMAZ =    1 /     1
 NO. OF PHOTON ESCAPE AZIMUTHAL ANGLE BINS                                / IKPMAZ =   1 /     1
1*********************************
 *   GEOMETRY DEPENDENT INPUT    *
 *********************************
ONUMBER OF INPUT ZONES =    1
0                    LEFT          RIGHT         INNER         OUTER        ELECTRON     PHOTON
```

```
1 ****************************************
  *                                      *
  *     PROGRAM ITS  - DECEMBER 16, 1984 *
  *             VERSION 1.0              *
  *                                      *
  ****************************************
  *          C Y L T R A N               *
  *          -------------               *
  ****************************************
ONUMBER OF MATERIALS
       2
O*********************************************************
 * GAMMA RAY CROSS SECTION DATA FOR MATERIAL NUMBER    1  *
 *********************************************************
OMPAIR  NTAB  MTAX
    25     6    39     7     3     2     3     4
OENERGIES (MEV)
 1000.000000  600.000000  600.000000  500.000000  400.000000  300.000000
  200.000000  150.000000  100.000000   80.000000   60.000000   50.000000
   40.000000   30.000000   20.000000   15.000000   10.000000    8.000000
    6.000000    5.000000    4.000000    3.000000    2.000000    1.500000
    1.000000    0.800000    0.600000    0.500000    0.400000    0.300000
    0.200000    0.150000    0.100000    0.080000    0.060000    0.050000
    0.040000    0.030000    0.027940
    0.027940    0.020000    0.015000    0.010000    0.008000    0.006000
    0.004238
    0.004238    0.004000    0.003938
    0.003938    0.003730
    0.003730    0.003000    0.002144
    0.002144    0.002000    0.001500    0.001000
OTOTAL ATTENUATION COEFFICIENTS (CM2/G)
    0.072765    0.072086    0.071064    0.070308    0.069253    0.067681
    0.064989    0.062724    0.059391    0.056593    0.053592    0.051730
    0.049243    0.045587    0.040515    0.038040    0.035902    0.035012
    0.034265    0.034193    0.034702    0.036525    0.041606    0.047119
    0.058324    0.066125    0.078504    0.088619    0.105375    0.140815
    0.256863    0.459567    1.231901    2.221800    4.849174    7.973909
   14.587593   31.164482   37.392754
    6.399423   16.079271   35.586170  108.562369  199.314251  430.412449
 1051.376794
  926.192751 1076.239060 1120.238487
  848.410361  973.346916
  400.500743  709.298048 1633.529058
 1127.930930 1332.818662 2623.326525 6389.511380
ORATIO OF SCATTERING PLUS PAIR PRODUCTION TO TOTAL ATTENUATION COEFFICIENTS
    0.999991    0.999988    0.999984    0.999980    0.999975    0.999966
    0.999947    0.999926    0.999882    0.999845    0.999781    0.999726
    0.999637    0.999471    0.999084    0.998666    0.997771    0.997034
    0.995702    0.994574    0.992817    0.989768    0.983155    0.975570
    0.956872    0.938869    0.900503    0.862535    0.794654    0.663924
    0.418614    0.255285    0.105735    0.061530    0.029729    0.018604
    0.010481    0.005065    0.004250
    0.024833    0.010154    0.004670    0.001559    0.000855    0.000399
    0.000165
    0.000187    0.000161    0.000155
    0.000204    0.000178
    0.000433    0.000245    0.000107
    0.000155    0.000131    0.000067    0.000027
ORATIO OF SCATTERING TO SCATTERING PLUS PAIR PRODUCTION ATTENUATION COEFFICIENTS
    0.002922    0.003679    0.004958    0.005997    0.007578    0.010266
    0.015819    0.021566    0.033314    0.042926    0.058763    0.071528
    0.091183    0.125583    0.196442    0.261915    0.376217    0.453464
    0.567301    0.643989    0.736247    0.841514    0.945837    0.986533
    1.000000
```

```
 0K SHELL IONIZATION DATA
 0BINDING ENERGY (MEV), PHOTOEFFECT EFFICIENCY AND FLUORESCENT EFFICIENCY
     0.027940     0.832399     0.827839
 0K X-RAY ENERGIES (MEV)
     0.024710     0.024710     0.024710     0.024710
 0K X-RAY ACCUMULATED RELATIVE INTENSITIES
     1.000000     1.000000     1.000000     1.000000
 0AUGER ELECTRON ENERGIES (MEV)
     0.024710     0.024710     0.024710
 0AUGER ELECTRON ACCUMULATED RELATIVE INTENSITIES
     1.000000     1.000000     1.000000
 0*.**************************************************
  * GAMMA RAY CROSS SECTION DATA FOR MATERIAL NUMBER   2 *
  **************************************************
 0MPAIR   NTAB  MTAX
       25     9    41      2      8      3      2      2      2      2      2
 0ENERGIES (MEV)
  1000.000000  800.000000  600.000000  500.000000  400.000000  300.000000
   200.000000  150.000000  100.000000   80.000000   60.000000   50.000000
    40.000000   30.000000   20.000000   15.000000   10.000000    8.000000
     6.000000    5.000000    4.000000    3.000000    2.000000    1.500000
     1.000000    0.800000    0.600000    0.500000    0.400000    0.300000
     0.200000    0.150000    0.100000    0.080000    0.060000    0.050000
     0.040000    0.030000    0.020000    0.015000    0.011867
     0.011867    0.010367
     0.010367    0.010000    0.008000    0.006000    0.004000    0.003000
     0.002000    0.001530
     0.001530    0.001500    0.001359
     0.001359    0.001323
     0.001323    0.001300
     0.001300    0.001142
     0.001142    0.001115
     0.001115    0.001000
 0TOTAL ATTENUATION COEFFICIENTS (CM2/G)
     0.060173    0.059621    0.058788    0.058165    0.057303    0.056005
     0.053787    0.051934    0.048963    0.046697    0.044178    0.042643
     0.040706    0.038095    0.034773    0.033158    0.031708    0.031226
     0.031146    0.031548    0.032637    0.035130    0.040841    0.046461
     0.056969    0.063728    0.073495    0.080568    0.090771    0.108617
     0.156168    0.232022    0.519524    0.897401    1.931400    3.204058
     6.011995   13.582092   42.219955   92.061788  169.049007
    88.555587  125.134417
    32.240310   35.706283   66.753770  147.467145  443.091478  955.117843
  2732.050663 5257.113182
  4921.179093 5143.463319 6436.545700
  5490.863273 5988.838578
  3846.426669 3993.258492
  3525.331716 4840.813860
  3578.786478 3983.385737
  1390.333237 1775.183143
 0RATIO OF SCATTERING PLUS PAIR PRODUCTION TO TOTAL ATTENUATION COEFFICIENTS
     0.999996    0.999995    0.999994    0.999992    0.999990    0.999987
     0.999980    0.999972    0.999955    0.999941    0.999916    0.999895
     0.999862    0.999801    0.999667    0.999525    0.999223    0.998982
     0.998566    0.998229    0.997722    0.996868    0.995042    0.992921
     0.987487    0.982006    0.969600    0.956339    0.929900    0.867642
     0.694056    0.509703    0.252731    0.153559    0.075239    0.046670
     0.025634    0.011714    0.003898    0.001820    0.001002
     0.001913    0.001361
     0.005284    0.004778    0.002575    0.001174    0.000394    0.000183
     0.000064    0.000034
     0.000036    0.000034    0.000027
     0.000032    0.000029
     0.000046    0.000044
```

```
         1          1    0.000e+00  2.970e-03  0.000e+00  9.525e-01    0.0000e+00 99-6.1100e-04  5-5.0719e-04  3-1.1182e-03  3
                                                                 TOTAL    0.0000e+00 99-6.1100e-04  5-5.0719e-04  3-1.1182e-03  3

1FLUX CALCULATION - ELECTRONS LEFT AT FLUX CUTOFF ENERGY (NUMBER, NORMALIZED TO ONE INCIDENT PARTICLE)
 1
 2.70e-05 20
1                                                ELECTRON FLUX DISTRIBUTION
                                    (TRACK-LENGTH/VOLUME-MEV, NORMALIZED TO ONE INCIDENT PARTICLE)
OE(MEV)  ZONE=     1

   27.0000   1.17e-01  0
   24.0000   9.54e-05  5
   21.0000   4.33e-05  7
   18.0000   2.72e-05  6
   15.0000   1.46e-05  8
   12.0000   1.12e-05 10
    9.0000   5.30e-06 15
    6.0000   5.71e-06  9
    3.0000   1.26e-05  9
    1.5000   4.92e-05  7
1                                                PHOTON FLUX DISTRIBUTION
                                    (TRACK-LENGTH/VOLUME-MEV, NORMALIZED TO ONE INCIDENT PARTICLE)
OE(MEV)  ZONE=     1

   27.0000   2.92e-06 16
   24.0000   5.43e-06 15
   21.0000   8.83e-06 16
   18.0000   9.23e-06 12
   15.0000   1.12e-05 15
   12.0000   1.51e-05 10
    9.0000   2.12e-05  7
    6.0000   3.39e-05  6
    3.0000   6.67e-05  5
    0.0100   1.10e-03  1

1                                    ENERGY SPECTRA OF TRANSMITTED ELECTRONS
                                    (NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)
       E (MEV)
   30.0000 -   27.0000  3.32e-01  0
   27.0000 -   24.0000  3.69e-04  3
   24.0000 -   21.0000  1.93e-04  3
   21.0000 -   18.0000  1.24e-04  5
   18.0000 -   15.0000  9.03e-05  5
   15.0000 -   12.0000  8.07e-05  8
   12.0000 -    9.0000  5.97e-05  7
    9.0000 -    6.0000  6.34e-05  7
    6.0000 -    3.0000  8.84e-05  6
    3.0000 -    1.5000  2.34e-04  7

0                                    ENERGY SPECTRA OF REFLECTED ELECTRONS
                                    (NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)
       E (MEV)
   30.0000 -   27.0000  0.00e+00 99
   27.0000 -   24.0000  2.97e-10 99
   24.0000 -   21.0000  0.00e+00 99
   21.0000 -   18.0000  0.00e+00 99
   18.0000 -   15.0000  0.00e+00 99
   15.0000 -   12.0000  3.59e-10 99
   12.0000 -    9.0000  3.35e-10 99
    9.0000 -    6.0000  1.13e-10 99
    6.0000 -    3.0000  3.82e-10 67
    3.0000 -    1.5000  3.49e-09 44
```

ENERGY SPECTRA OF LATERALLY ESCAPING ELECTRONS
(NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)

E (MEV)			
30.0000 -	27.0000	0.00e+00	99
27.0000 -	24.0000	0.00e+00	99
24.0000 -	21.0000	0.00e+00	99
21.0000 -	18.0000	0.00e+00	99
18.0000 -	15.0000	0.00e+00	99
15.0000 -	12.0000	0.00e+00	99
12.0000 -	9.0000	0.00e+00	99
9.0000 -	6.0000	0.00e+00	99
6.0000 -	3.0000	0.00e+00	99
3.0000 -	1.5000	0.00e+00	99

ANGULAR DISTRIBUTIONS OF TRANSMITTED AND REFLECTED ELECTRONS
(NUMBER/SR, NORMALIZED TO ONE INCIDENT PARTICLE)

0 PHI(DEG)= 0.000 180.000

THETA (DEG)			
0.0000 -	18.0000	3.25e+00	0
18.0000 -	36.0000	4.07e-04	6
36.0000 -	54.0000	8.63e-05	13
54.0000 -	72.0000	9.71e-06	25
72.0000 -	90.0000	1.03e-06	67
90.0000 -	108.0000	2.04e-09	76
108.0000 -	126.0000	2.30e-09	50
126.0000 -	144.0000	1.18e-09	71
144.0000 -	162.0000	0.00e+00	99
162.0000 -	180.0000	0.00e+00	99

ANGULAR DISTRIBUTIONS OF LATERALLY ESCAPING ELECTRONS
(NUMBER/SR, NORMALIZED TO ONE INCIDENT PARTICLE)

0 PHI(DEG)= 0.000 180.000

THETA (DEG)			
0.0000 -	18.0000	0.00e+00	99
18.0000 -	36.0000	0.00e+00	99
36.0000 -	54.0000	0.00e+00	99
54.0000 -	72.0000	0.00e+00	99
72.0000 -	90.0000	0.00e+00	99
90.0000 -	108.0000	0.00e+00	99
108.0000 -	126.0000	0.00e+00	99
126.0000 -	144.0000	0.00e+00	99
144.0000 -	162.0000	0.00e+00	99
162.0000 -	180.0000	0.00e+00	99

0 ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF ELECTRONS TRANSMITTED AND REFLECTED
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

0 E (MEV)		THETA= 0.000 18.000	18.000 36.000	36.000 54.000	54.000 72.000	72.000 90.000	90.000 108.000	108.000 126.000	126.000 144.000	144.000 162.000
30.0000 -	27.0000	1.08e+00 0	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
27.0000 -	24.0000	1.20e-03 3	0.00e+00 99	6.60e-11 99	1.89e-11 99	0.00e+00 99	0.00e+00 99	1.69e-10 99	0.00e+00 99	0.00e+00 99
24.0000 -	21.0000	6.27e-04 3	3.60e-10 94	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
21.0000 -	18.0000	4.03e-04 5	2.16e-10 65	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
18.0000 -	15.0000	2.94e-04 5	4.91e-10 87	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
15.0000 -	12.0000	2.62e-04 8	2.66e-10 99	4.15e-10 45	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
12.0000 -	9.0000	1.93e-04 7	3.75e-07 99	1.82e-10 72	0.00e+00 99	0.00e+00 99	0.00e+00 99	2.58e-10 99	0.00e+00 99	0.00e+00 99
9.0000 -	6.0000	1.77e-04 7	1.01e-05 24	7.01e-10 47	1.31e-10 99	0.00e+00 99	0.00e+00 99	6.47e-11 99	0.00e+00 99	0.00e+00 99
6.0000 -	3.0000	1.22e-04 6	5.64e-05 7	4.81e-07 99	3.48e-10 57	1.33e-10 80	9.07e-11 99	0.00e+00 99	1.34e-10 99	0.00e+00 99
3.0000 -	1.5000	6.34e-05 23	1.38e-04 8	5.66e-05 12	6.47e-06 25	6.87e-07 67	8.35e-10 64	1.07e-09 48	0.00e+00 99	0.00e+00 99

0 ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF ELECTRONS TRANSMITTED AND REFLECTED

ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF PHOTONS TRANSMITTED AND REFLECTED
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

E (MEV)	THETA= 0.000 18.000	18.000 36.000	36.000 54.000	54.000 72.000	72.000 90.000	90.000 108.000	108.000 126.000	126.000 144.000	144.000 162.000
30.0000 - 27.0000	4.98e-05 15	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
27.0000 - 24.0000	1.01e-04 7	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
24.0000 - 21.0000	1.44e-04 10	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
21.0000 - 18.0000	1.63e-04 7	3.73e-07 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
18.0000 - 15.0000	2.36e-04 10	3.73e-07 99	2.40e-07 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
15.0000 - 12.0000	2.92e-04 5	3.73e-07 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
12.0000 - 9.0000	4.03e-04 5	1.22e-10 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
9.0000 - 6.0000	6.23e-04 3	7.47e-07 67	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
6.0000 - 3.0000	1.18e-03 3	2.62e-06 30	2.40e-07 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
3.0000 - 0.0100	9.27e-03 1	1.06e-04 6	8.74e-05 5	7.99e-05 5	5.15e-05 2	5.68e-05 5	8.71e-05 5	8.27e-05 5	9.05e-05 5
INTEGRAL (/SR)	3.73e-02 1	3.32e-04 6	2.63e-04 5	2.39e-04 5	1.54e-04 2	1.70e-04 5	2.61e-04 5	2.47e-04 5	2.70e-04 5

ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF PHOTONS TRANSMITTED AND REFLECTED
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

E (MEV)	THETA=162.000 180.000
30.0000 - 27.0000	0.00e+00 99
27.0000 - 24.0000	0.00e+00 99
24.0000 - 21.0000	0.00e+00 99
21.0000 - 18.0000	0.00e+00 99
18.0000 - 15.0000	0.00e+00 99
15.0000 - 12.0000	0.00e+00 99
12.0000 - 9.0000	0.00e+00 99
9.0000 - 6.0000	0.00e+00 99
6.0000 - 3.0000	0.00e+00 99
3.0000 - 0.0100	9.26e-05 6
INTEGRAL (/SR)	2.77e-04 6

ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF PHOTONS LATERALLY ESCAPING
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

E (MEV)	THETA= 0.000 18.000	18.000 36.000	36.000 54.000	54.000 72.000	72.000 90.000	90.000 108.000	108.000 126.000	126.000 144.000	144.000 162.000
30.0000 - 27.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
27.0000 - 24.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
24.0000 - 21.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
21.0000 - 18.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
18.0000 - 15.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
15.0000 - 12.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
12.0000 - 9.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
9.0000 - 6.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
6.0000 - 3.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99
3.0000 - 0.0100	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	1.34e-10 67	2.79e-10 71	0.00e+00 99	0.00e+00 99	0.00e+00 99
INTEGRAL (/SR)	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	4.00e-10 67	8.35e-10 71	0.00e+00 99	0.00e+00 99	0.00e+00 99

ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF PHOTONS LATERALLY ESCAPING
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

E (MEV)	THETA=162.000 180.000
30.0000 - 27.0000	0.00e+00 99
27.0000 - 24.0000	0.00e+00 99
24.0000 - 21.0000	0.00e+00 99

21.0000 -	18.0000	0.00e+00	99
18.0000 -	15.0000	0.00e+00	99
15.0000 -	12.0000	0.00e+00	99
12.0000 -	9.0000	0.00e+00	99
9.0000 -	6.0000	0.00e+00	99
6.0000 -	3.0000	0.00e+00	99
3.0000 -	0.0100	0.00e+00	99
o INTEGRAL (/SR)		0.00e+00	99

THE NUMBER OF DATA FOR WHICH STATISTICAL ESTIMATES HAVE BEEN PROVIDED IS 588

```
ECHO 1
TITLE
...100.0 MEV TEST PROGRAM
**********************SOURCE**********************
ELECTRONS
ENERGY 100.0
* DEFAULT SOURCE PHASE SPACE PARAMETERS
* POSITION 0.0 0.0 0.0
SOURCE-RADIUS 0.95250
* MONODIRECTIONAL Z AXIS
**********************OTHER OPTIONS*****************
HISTORIES 1000000
BATCHES 10
CUTOFFS 0.05 0.001
**********************OUTPUT OPTIONS****************
ELECTRON-ESCAPE
NBINE 10
NBINT 10
PHOTON-ESCAPE
NBINE 10
NBINT 10
ELECTRON-FLUX 1 1
NBINE 10
PHOTON-FLUX 1 1
NBINE 10
**********************GEOMETRY**********************
GEOMETRY 1
*ZL        ZR        RI        RO MAT   IZR   NZ    NR  ECUT  PICZ
0.0 0.00297 0.0 0.95250 1 1 1 1 0.0 0.5
```

```
1 ****************************************
  *                                      *
  *    PROGRAM XGEN - DECEMBER  1, 1984  *
  *            VERSION 1.0               *
  *                                      *
  ****************************************
   END OF FILE ON UNIT 5 - XGEN
          ----------------------
           SUMMARY OF INPUT DATA
          ----------------------
OMAXIMUM CROSS SECTION ENERGY =   1.0000e+02
OMATERIAL 1       SOLID/LIQUID
        DENSITY          3.9650e+00
        DENSITY-RATIO    1.0000e+00
       SYMBOL  ATOMIC NUMBER   WEIGHT FRACTION
 ------------------------------------------------
   1      O          8             4.7100e-01
   2      AL        13             5.2900e-01
O ************************************************************
  *                                                          *
  *  BEGIN EXECUTING PHOTON CROSS SECTION SUBROUTINE - PGEN  *
  *                                                          *
  ************************************************************
OEND OF PGEN SUBROUTINE
O************************************************************
 *                                                          *
 * BEGIN EXECUTING ELECTRON CROSS SECTION SUBROUTINE - DATPAC *
 *                                                          *
 ************************************************************


 100.0 MEV CROSS SECTIONS SAPPHIRE
1*****************************************************
 *  ELECTRON CROSS SECTIONS FOR MATERIAL NUMBER  1  *
 *****************************************************
O ITRM  IZIP  ISGN  ISUB  INEL  ICYC  NCYC  NMAX              EMAX
     5     0     1    40     1     1     8    64     1.00000e+02
OINPUT DATA TAPE IDENTIFICATION
 DATATAPE-2 (RESIER-AIGINGER PH-RAD CORR), 54 STERNHEIMER SETS. 30 JAN 6
ODETOUR         DENSITY
  7.31000e-01  3.96500e+00
O
ORANGE TABLE
O      EMAX       NCYC       EFAC       NMAX     T(NMAX+1)    NCAL      T(NCAL)
    1.00000e+02      8    9.17004e-01     64    3.90625e-01    134    9.89410e-04
O JMAX  LMAX
     2     1
O       Z             A             W
      8.00000      15.99939      0.47100
     13.00000      26.98148      0.52900
O       PI            PID
    121.89239     121.89239
O   ---------------------PARAMETERS FOR DENSITY EFFECT---------------------
        PI            C             A             DM            X1            XO

    121.89239     -3.22058      0.10475      3.00000      3.00000      0.20000
    121.89239     -3.22058      0.10475      3.00000      3.00000      0.20000
!                                          ELECTRON RESULTS
O     EFFECTIVE Z/A = 0.49039     EFFECTIVE MEAN IONIZATION POTENTIAL =  121.89 EV     CRITICAL ENERGY =  59.572 MEV
O       ENERGY          STOPPING POWER            RANGE   RADIATION   BETA**2   DENSITY   RAD/COL   DRANGE    DYIELD
    N              COLLISION RADIATION   TOTAL              YIELD                 CORR
          MEV      MEV CM2/G MEV CM2/G MEV CM2/G   G/CM2                       MEV CM2/G              G/CM2
```

134	9.8941e-04	8.762e+01	7.462e-03	8.762e+01	5.646e-06	0.000e+00	3.861e-03	0.000e+00	8.517e-05	5.646e-06	0.000e+00	
133	1.0790e-03	8.346e+01	7.458e-03	8.347e+01	6.693e-06	7.242e-08	4.210e-03	0.000e+00	8.938e-05	1.047e-06	7.814e-09	
132	1.1766e-03	7.940e+01	7.453e-03	7.940e+01	7.893e-06	1.424e-05	4.589e-03	0.000e+00	9.387e-05	1.200e-06	8.946e-09	
131	1.2831e-03	7.543e+01	7.448e-03	7.544e+01	9.270e-06	2.105e-05	5.003e-03	0.000e+00	9.873e-05	1.376e-06	1.026e-08	
130	1.3992e-03	7.158e+01	7.442e-03	7.159e+01	1.085e-05	2.772e-05	5.454e-03	0.000e+00	1.040e-04	1.581e-06	1.177e-08	
129	1.5259e-03	6.786e+01	7.435e-03	6.786e+01	1.267e-05	3.428e-05	5.946e-03	0.000e+00	1.096e-04	1.818e-06	1.352e-08	
128	1.6640e-03	6.426e+01	7.428e-03	6.427e+01	1.478e-05	4.078e-05	6.481e-03	0.000e+00	1.156e-04	2.092e-06	1.555e-08	
127	1.8146e-03	6.080e+01	7.420e-03	6.080e+01	1.717e-05	4.725e-05	7.065e-03	0.000e+00	1.221e-04	2.410e-06	1.789e-08	
126	1.9788e-03	5.747e+01	7.411e-03	5.747e+01	1.995e-05	5.375e-05	7.700e-03	0.000e+00	1.290e-04	2.780e-06	2.061e-08	
125	2.1579e-03	5.427e+01	7.402e-03	5.428e+01	2.316e-05	6.030e-05	8.393e-03	0.000e+00	1.364e-04	3.208e-06	2.376e-08	
124	2.3532e-03	5.122e+01	7.391e-03	5.123e+01	2.686e-05	6.694e-05	9.147e-03	0.000e+00	1.443e-04	3.706e-06	2.741e-08	
123	2.5662e-03	4.830e+01	7.381e-03	4.831e+01	3.115e-05	7.371e-05	9.969e-03	0.000e+00	1.528e-04	4.283e-06	3.164e-08	
122	2.7985e-03	4.552e+01	7.368e-03	4.553e+01	3.610e-05	8.065e-05	1.086e-02	0.000e+00	1.619e-04	4.955e-06	3.654e-08	
121	3.0518e-03	4.287e+01	7.355e-03	4.288e+01	4.184e-05	8.779e-05	1.184e-02	0.000e+00	1.715e-04	5.735e-06	4.222e-08	
120	3.3280e-03	4.035e+01	7.340e-03	4.036e+01	4.848e-05	9.517e-05	1.290e-02	0.000e+00	1.819e-04	6.643e-06	4.881e-08	
119	3.6292e-03	3.796e+01	7.324e-03	3.797e+01	5.618e-05	1.028e-04	1.405e-02	0.000e+00	1.930e-04	7.699e-06	5.645e-08	
118	3.9576e-03	3.569e+01	7.308e-03	3.570e+01	6.511e-05	1.108e-04	1.531e-02	0.000e+00	2.047e-04	8.927e-06	6.531e-08	
117	4.3158e-03	3.354e+01	7.290e-03	3.355e+01	7.546e-05	1.191e-04	1.668e-02	0.000e+00	2.173e-04	1.036e-05	7.559e-08	
116	4.7065e-03	3.151e+01	7.270e-03	3.151e+01	8.748e-05	1.278e-04	1.817e-02	0.000e+00	2.308e-04	1.202e-05	8.751e-08	
115	5.1324e-03	2.958e+01	7.250e-03	2.959e+01	1.014e-04	1.370e-04	1.979e-02	0.000e+00	2.451e-04	1.396e-05	1.013e-07	
114	5.5969e-03	2.776e+01	7.228e-03	2.777e+01	1.177e-04	1.466e-04	2.155e-02	0.000e+00	2.603e-04	1.621e-05	1.174e-07	
113	6.1035e-03	2.605e+01	7.205e-03	2.606e+01	1.365e-04	1.567e-04	2.347e-02	0.000e+00	2.766e-04	1.884e-05	1.360e-07	
112	6.6559e-03	2.443e+01	7.182e-03	2.444e+01	1.584e-04	1.673e-04	2.555e-02	0.000e+00	2.940e-04	2.190e-05	1.576e-07	
111	7.2583e-03	2.291e+01	7.157e-03	2.291e+01	1.839e-04	1.786e-04	2.782e-02	0.000e+00	3.124e-04	2.547e-05	1.826e-07	
110	7.9153e-03	2.147e+01	7.131e-03	2.148e+01	2.135e-04	1.905e-04	3.028e-02	0.000e+00	3.321e-04	2.963e-05	2.117e-07	
109	8.6317e-03	2.012e+01	7.104e-03	2.013e+01	2.480e-04	2.031e-04	3.295e-02	0.000e+00	3.531e-04	3.447e-05	2.454e-07	
108	9.4129e-03	1.885e+01	7.077e-03	1.886e+01	2.881e-04	2.165e-04	3.585e-02	0.000e+00	3.754e-04	4.012e-05	2.845e-07	
107	1.0265e-02	1.766e+01	7.049e-03	1.767e+01	3.348e-04	2.307e-04	3.900e-02	0.000e+00	3.991e-04	4.670e-05	3.298e-07	
106	1.1194e-02	1.654e+01	7.021e-03	1.655e+01	3.892e-04	2.457e-04	4.241e-02	0.000e+00	4.244e-04	5.437e-05	3.824e-07	
105	1.2207e-02	1.549e+01	6.992e-03	1.550e+01	4.525e-04	2.616e-04	4.612e-02	0.000e+00	4.513e-04	6.330e-05	4.435e-07	
104	1.3312e-02	1.451e+01	6.962e-03	1.451e+01	5.262e-04	2.785e-04	5.014e-02	0.000e+00	4.799e-04	7.371e-05	5.142e-07	
103	1.4517e-02	1.358e+01	6.933e-03	1.359e+01	6.120e-04	2.965e-04	5.449e-02	0.000e+00	5.104e-04	8.584e-05	5.963e-07	
102	1.5831e-02	1.272e+01	6.903e-03	1.273e+01	7.120e-04	3.156e-04	5.920e-02	0.000e+00	5.428e-04	9.997e-05	6.915e-07	
101	1.7263e-02	1.191e+01	6.874e-03	1.192e+01	8.284e-04	3.358e-04	6.429e-02	0.000e+00	5.772e-04	1.164e-04	8.020e-07	
100	1.8826e-02	1.115e+01	6.845e-03	1.116e+01	9.640e-04	3.574e-04	6.980e-02	0.000e+00	6.138e-04	1.356e-04	9.300e-07	
99	2.0530e-02	1.044e+01	6.817e-03	1.045e+01	1.122e-03	3.802e-04	7.576e-02	0.000e+00	6.527e-04	1.579e-04	1.078e-06	
98	2.2388e-02	9.782e+00	6.790e-03	9.789e+00	1.306e-03	4.045e-04	8.219e-02	0.000e+00	6.942e-04	1.838e-04	1.251e-06	
97	2.4414e-02	9.163e+00	6.764e-03	9.170e+00	1.520e-03	4.304e-04	8.912e-02	0.000e+00	7.382e-04	2.140e-04	1.450e-06	
96	2.6624e-02	8.586e+00	6.738e-03	8.592e+00	1.769e-03	4.578e-04	9.659e-02	0.000e+00	7.848e-04	2.491e-04	1.681e-06	
95	2.9033e-02	8.046e+00	6.715e-03	8.053e+00	2.059e-03	4.870e-04	1.046e-01	0.000e+00	8.345e-04	2.899e-04	1.950e-06	
94	3.1661e-02	7.543e+00	6.693e-03	7.550e+00	2.396e-03	5.180e-04	1.133e-01	0.000e+00	8.873e-04	3.372e-04	2.261e-06	
93	3.4527e-02	7.074e+00	6.674e-03	7.081e+00	2.788e-03	5.509e-04	1.226e-01	0.000e+00	9.434e-04	3.922e-04	2.621e-06	
92	3.7652e-02	6.637e+00	6.656e-03	6.644e+00	3.244e-03	5.859e-04	1.325e-01	0.000e+00	1.003e-03	4.559e-04	3.038e-06	
91	4.1059e-02	6.230e+00	6.642e-03	6.237e+00	3.774e-03	6.230e-04	1.432e-01	0.000e+00	1.066e-03	5.298e-04	3.522e-06	
90	4.4776e-02	5.851e+00	6.630e-03	5.857e+00	4.389e-03	6.625e-04	1.546e-01	0.000e+00	1.133e-03	6.153e-04	4.083e-06	
89	4.8828e-02	5.498e+00	6.621e-03	6.505e+00	5.103e-03	7.044e-04	1.668e-01	0.000e+00	1.204e-03	7.142e-04	4.731e-06	
88	5.3247e-02	5.170e+00	6.617e-03	5.176e+00	5.932e-03	7.489e-04	1.798e-01	0.000e+00	1.280e-03	8.284e-04	5.483e-06	
87	5.8067e-02	4.865e+00	6.616e-03	4.871e+00	6.892e-03	7.962e-04	1.937e-01	0.000e+00	1.360e-03	9.603e-04	6.353e-06	
86	6.3322e-02	4.581e+00	6.620e-03	4.588e+00	8.004e-03	8.463e-04	2.084e-01	0.000e+00	1.445e-03	1.112e-03	7.361e-06	
85	6.9053e-02	4.318e+00	6.629e-03	4.325e+00	9.292e-03	8.996e-04	2.239e-01	0.000e+00	1.535e-03	1.287e-03	8.528e-06	
84	7.5303e-02	4.074e+00	6.642e-03	4.081e+00	1.078e-02	9.561e-04	2.404e-01	0.000e+00	1.630e-03	1.489e-03	9.877e-06	
83	8.2119e-02	3.848e+00	6.663e-03	3.855e+00	1.250e-02	1.016e-03	2.577e-01	0.000e+00	1.732e-03	1.720e-03	1.144e-05	
82	8.9551e-02	3.638e+00	6.690e-03	3.645e+00	1.448e-02	1.080e-03	2.760e-01	0.000e+00	1.839e-03	1.984e-03	1.325e-05	
81	9.7656e-02	3.444e+00	6.723e-03	3.451e+00	1.677e-02	1.147e-03	2.952e-01	0.000e+00	1.952e-03	2.287e-03	1.534e-05	
80	1.0649e-01	3.264e+00	6.766e-03	3.271e+00	1.940e-02	1.219e-03	3.152e-01	0.000e+00	2.073e-03	2.632e-03	1.776e-05	
79	1.1613e-01	3.098e+00	6.819e-03	3.105e+00	2.243e-02	1.294e-03	3.361e-01	0.000e+00	2.201e-03	3.026e-03	2.055e-05	
78	1.2664e-01	2.945e+00	6.877e-03	2.952e+00	2.590e-02	1.375e-03	3.578e-01	0.000e+00	2.335e-03	3.474e-03	2.379e-05	
77	1.3811e-01	2.804e+00	6.951e-03	2.811e+00	2.989e-02	1.460e-03	3.803e-01	0.000e+00	2.479e-03	3.982e-03	2.753e-05	
76	1.5061e-01	2.674e+00	7.037e-03	2.681e+00	3.444e-02	1.551e-03	4.035e-01	0.000e+00	2.632e-03	4.556e-03	3.187e-05	
75	1.6424e-01	2.554e+00	7.138e-03	2.561e+00	3.965e-02	1.646e-03	4.273e-01	0.000e+00	2.795e-03	5.205e-03	3.689e-05	
74	1.7910e-01	2.444e+00	7.250e-03	2.451e+00	4.558e-02	1.748e-03	4.517e-01	0.000e+00	2.966e-03	5.936e-03	4.271e-05	
73	1.9531e-01	2.343e+00	7.383e-03	2.350e+00	5.234e-02	1.856e-03	4.766e-01	0.000e+00	3.151e-03	6.757e-03	4.944e-05	
72	2.1299e-01	2.251e+00	7.536e-03	2.258e+00	6.002e-02	1.971e-03	5.018e-01	0.000e+00	3.348e-03	7.677e-03	5.726e-05	

71	2.3227e-01	2.167e+00	7.711e-03	2.174e+00	6.872e-02	2.093e-03	5.274e-01	0.000e+00	3.559e-03	8.704e-03	6.636e 05
70	2.5329e-01	2.090e+00	7.902e-03	2.098e+00	7.857e-02	2.223e-03	5.530e 01	0.000e+00	3.781e-03	9.848e-03	7.689e 05
69	2.7621e-01	2.020e+00	8.128e-03	2.028e+00	8.969e-02	2.361e-03	5.787e-01	0.000e+00	4.024e-03	1.112e-02	8.912e-05
68	3.0121e-01	1.957e+00	8.386e-03	1.965e+00	1.022e-01	2.509e-03	6.042e-01	0.000e+00	4.285e-03	1.253e-02	1.034e-04
67	3.2848e-01	1.900e+00	8.674e-03	1.909e+00	1.163e-01	2.666e-03	6.295e-01	0.000e+00	4.565e-03	1.408e-02	1.201e-04
66	3.5820e-01	1.849e+00	9.003e-03	1.858e+00	1.321e-01	2.834e-03	6.544e-01	0.000e+00	4.869e-03	1.579e-02	1.396e 04
65	3.9063e-01	1.803e+00	9.376e-03	1.812e+00	1.498e-01	3.015e-03	6.788e-01	0.000e+00	5.200e-03	1.767e-02	1.624e-04
64	4.2598e-01	1.762e+00	9.796e-03	1.772e+00	1.695e-01	3.209e-03	7.026e-01	0.000e+00	5.558e-03	1.973e-02	1.892e-04
63	4.6453e-01	1.724e+00	1.027e-02	1.734e+00	1.915e-01	3.417e-03	7.256e-01	2.499e-03	5.958e-03	2.199e-02	2.206e-04
62	5.0658e-01	1.687e+00	1.081e-02	1.698e+00	2.160e-01	3.644e-03	7.478e-01	7.895e-03	6.406e-03	2.451e-02	2.583e-04
61	5.5243e-01	1.654e+00	1.141e-02	1.666e+00	2.433e-01	3.890e-03	7.691e-01	1.318e-02	6.898e-03	2.727e-02	3.030e-04
60	6.0243e-01	1.626e+00	1.209e 02	1.638e+00	2.736e-01	4.158e 03	7.894e-01	1.839e-02	7.439e-03	3.028e-02	3.558e-04
59	6.5695e-01	1.601e+00	1.286e-02	1.614e+00	3.071e-01	4.450e-03	8.086e 01	2.356e-02	8.035e-03	3.355e-02	4.186e-04
58	7.1641e-01	1.579e+00	1.373e-02	1.593e+00	3.442e-01	4.769e-03	8.267e-01	2.871e-02	8.693e-03	3.710e-02	4.931e-04
57	7.8125e-01	1.561e+00	1.470e-02	1.575e+00	3.851e-01	5.118e-03	8.436e-01	3.388e-02	9.418e-03	4.094e-02	5.819e-04
56	8.5196e-01	1.545e+00	1.579e-02	1.561e+00	4.302e-01	5.500e-03	8.594e-01	3.908e-02	1.022e-02	4.510e-02	6.874e-04
55	9.2907e-01	1.532e+00	1.701e-02	1.549e+00	4.798e-01	5.919e-03	8.741e-01	4.435e-02	1.110e-02	4.959e-02	8.133e-04
54	1.0132e+00	1.522e+00	1.839e-02	1.540e+00	5.343e-01	6.378e-03	8.876e-01	4.970e-02	1.208e-02	5.444e-02	9.635e-04
53	1.1049e+00	1.514e+00	1.993e-02	1.534e+00	5.940e-01	6.884e-03	9.000e-01	5.515e-02	1.317e-02	5.967e-02	1.143e 03
52	1.2049e+00	1.508e+00	2.166e-02	1.529e+00	6.593e-01	7.439e-03	9.113e-01	6.072e-02	1.437e-02	6.531e-02	1.358e 03
51	1.3139e+00	1.503e+00	2.362e-02	1.527e+00	7.306e-01	8.051e-03	9.216e 01	6.643e-02	1.571e-02	7.137e 02	1.616e 03
50	1.4328e+00	1.501e+00	2.579e-02	1.526e+00	8.085e-01	8.726e-03	9.309e 01	7.227e-02	1.719e-02	7.790e 02	1.924e 03
49	1.5625e+00	1.500e+00	2.822e-02	1.528e+00	8.935e-01	9.469e-03	9.393e-01	7.828e-02	1.882e-02	8.492e-02	2.293e-03
48	1.7039e+00	1.500e+00	3.094e-02	1.531e+00	9.859e-01	1.029e-02	9.468e 01	8.445e-02	2.063e-02	9.248e-02	2.735e-03
47	1.8581e+00	1.501e+00	3.400e-02	1.535e+00	1.087e+00	1.119e-02	9.535e-01	9.080e-02	2.264e-02	1.006e 01	3.266e-03
46	2.0263e+00	1.504e+00	3.739e-02	1.541e+00	1.196e+00	1.219e-02	9.594e-01	9.733e-02	2.486e-02	1.093e-01	3.901e-03
45	2.2097e+00	1.508e+00	4.117e-02	1.549e+00	1.315e+00	1.329e-02	9.647e-01	1.040e-01	2.731e-02	1.187e-01	4.661e-03
44	2.4097e+00	1.512e+00	4.538e-02	1.557e+00	1.443e+00	1.450e-02	9.694e-01	1.110e-01	3.001e-02	1.288e-01	5.571e-03
43	2.6278e+00	1.517e+00	5.012e-02	1.567e+00	1.583e+00	1.583e-02	9.735e-01	1.181e-01	3.303e-02	1.396e-01	6.666e-03
42	2.8656e+00	1.523e+00	5.535e-02	1.578e+00	1.734e+00	1.730e-02	9.771e-01	1.253e-01	3.634e-02	1.512e-01	7.972e-03
41	3.1250e+00	1.530e+00	6.118e-02	1.591e+00	1.898e+00	1.891e-02	9.803e-01	1.328e-01	4.000e-02	1.637e-01	9.535e-03
40	3.4078e+00	1.536e+00	6.768e-02	1.604e+00	2.075e+00	2.069e-02	9.830e-01	1.405e-01	4.405e 02	1.771e-01	1.141e-02
39	3.7163e+00	1.544e+00	7.489e-02	1.619e+00	2.266e+00	2.264e-02	9.854e-01	1.484e-01	4.852e-02	1.914e-01	1.364e-02
38	4.0526e+00	1.551e+00	8.290e-02	1.634e+00	2.473e+00	2.479e-02	9.875e-01	1.565e-01	5.343e-02	2.068e-01	1.631e-02
37	4.4194e+00	1.559e+00	9.179e-02	1.651e+00	2.696e+00	2.714e-02	9.893e-01	1.647e 01	5.886e-02	2.233e-01	1.950e-02
36	4.8194e+00	1.567e+00	1.016e-01	1.669e+00	2.937e+00	2.973e-02	9.908e-01	1.732e-01	6.484e-02	2.409e-01	2.330e-02
35	5.2556e+00	1.576e+00	1.126e-01	1.688e+00	3.197e+00	3.255e-02	9.921e-01	1.818e-01	7.143e-02	2.598e-01	2.782e-02
34	5.7313e+00	1.584e+00	1.247e-01	1.709e+00	3.477e+00	3.564e-02	9.933e-01	1.906e-01	7.870e-02	2.800e-01	3.321e-02
33	6.2500e+00	1.593e+00	1.381e-01	1.731e+00	3.779e+00	3.902e-02	9.943e-01	1.996e-01	8.669e-02	3.016e-01	3.962e-02
32	6.8157e+00	1.602e+00	1.529e-01	1.755e+00	4.103e+00	4.271e-02	9.951e-01	2.088e-01	9.549e-02	3.246e-01	4.722e-02
31	7.4325e+00	1.610e+00	1.694e-01	1.780e+00	4.452e+00	4.674e-02	9.959e-01	2.181e-01	1.052e-01	3.491e-01	5.625e-02
30	8.1052e+00	1.619e+00	1.876e-01	1.807e+00	4.828e+00	5.112e-02	9.965e-01	2.276e-01	1.158e-01	3.751e-01	6.693e-02
29	8.8388e+00	1.628e+00	2.076e-01	1.836e+00	5.230e+00	5.588e-02	9.970e-01	2.373e-01	1.275e-01	4.028e-01	7.957e-02
28	9.6388e+00	1.637e+00	2.298e-01	1.867e+00	5.663e+00	6.104e-02	9.975e-01	2.471e-01	1.404e-01	4.322e-01	9.451e-02
27	1.0511e+01	1.645e+00	2.543e-01	1.900e+00	6.126e+00	6.664e-02	9.979e-01	2.571e-01	1.546e-01	4.632e-01	1.121e 01
26	1.1463e+01	1.654e+00	2.814e-01	1.936e+00	6.622e+00	7.270e-02	9.982e-01	2.672e-01	1.701e-01	4.961e-01	1.328e-01
25	1.2500e+01	1.663e+00	3.112e-01	1.974e+00	7.153e+00	7.924e-02	9.985e-01	2.775e-01	1.871e-01	5.307e 01	1.572e-01
24	1.3631e+01	1.672e+00	3.441e-01	2.016e+00	7.720e+00	8.630e-02	9.987e 01	2.878e-01	2.059e-01	5.671e-01	1.858e 01
23	1.4865e+01	1.680e+00	3.804e-01	2.060e+00	8.325e+00	9.388e-02	9.989e-01	2.984e-01	2.264e-01	6.054e-01	2.192e-01
22	1.6210e+01	1.689e+00	4.203e-01	2.109e+00	8.970e+00	1.020e-01	9.991e-01	3.090e-01	2.489e-01	6.454e 01	2.583e 01
21	1.7678e+01	1.697e+00	4.643e-01	2.161e+00	9.658e+00	1.107e-01	9.992e-01	3.198e-01	2.736e 01	6.872e-01	3.038e 01
20	1.9278e+01	1.705e+00	5.127e-01	2.218e+00	1.039e+01	1.201e-01	9.993e-01	3.307e 01	3.006e-01	7.307e 01	3 568e 01
19	2.1022e+01	1.714e+00	5.659e-01	2.280e+00	1.116e+01	1.300e-01	9.994e 01	3.417e-01	3.302e-01	7.759e-01	4.183e 01
18	2.2925e+01	1.722e+00	6.245e-01	2.346e+00	1.199e+01	1.406e-01	9.995e 01	3.529e-01	3.627e-01	8.227e-01	4.895e 01
17	2.5000e+01	1.730e+00	6.889e-01	2.419e+00	1.286e+01	1.518e-01	9.996e-01	3.641e-01	3.982e-01	8.709e-01	5.717e-01
16	2.7263e+01	1.738e+00	7.596e-01	2.498e+00	1.378e+01	1.636e-01	9.997e-01	3.755e-01	4.371e-01	9.205e-01	6.665e 01
15	2.9730e+01	1.746e+00	8.374e-01	2.583e+00	1.475e+01	1.761e-01	9.997e-01	3.869e-01	4.796e-01	9.713e-01	7.754e 01
14	3.2421e+01	1.754e+00	9.228e-01	2.677e+00	1.577e+01	1.893e-01	9.998e-01	3.985e-01	5.261e-01	1.023e+00	9.002e-01
13	3.5355e+01	1.762e+00	1.017e+00	2.778e+00	1.685e+01	2.031e-01	9.998e 01	4.101e-01	5.770e-01	1.076e+00	1.043e+00
12	3.8555e+01	1.769e+00	1.119e+00	2.889e+00	1.798e+01	2.175e 01	9.998e-01	4.219e-01	6.326e-01	1.129e+00	1.206e+00
11	4.2045e+01	1.777e+00	1.232e+00	3.009e+00	1.916e+01	2.325e-01	9.999e 01	4.337e-01	6.934e-01	1.183e+00	1.391e+00
10	4.5850e+01	1.785e+00	1.356e+00	3.141e+00	2.040e+01	2.481e-01	9.999e-01	4.456e 01	7.598e 01	1.238e+00	1.601e+00
9	5.0000e+01	1.792e+00	1.492e+00	3.284e+00	2.169e+01	2.643e 01	9.999e-01	4.576e 01	8.324e-01	1.292e+00	1 839e+00
8	5.4525e+01	1.800e+00	1.641e+00	3.440e+00	2.304e+01	2.810e-01	9.999e-01	4.696e-01	9.116e-01	1.346e+00	2.108e+00

7	5.9460e+01	1.807e+00	1.804e+00	3.611e+00	2.444e+01	2.982e-01	9.999e-01	4.818e-01	9.980e-01	1.400e+00	2.410e+00
6	6.4842e+01	1.814e+00	1.982e+00	3.797e+00	2.589e+01	3.159e-01	9.999e 01	4.940e-01	1.092e+00	1.453e+00	2.750e+00
5	7.0711e+01	1.822e+00	2.178e+00	3.999e+00	2.740e+01	3.340e-01	9.999e-01	5.063e-01	1.195e+00	1.506e+00	3.131e+00
4	7.7111e+01	1.829e+00	2.392e+00	4.221e+00	2.895e+01	3.524e-01	1.000e+00	5.186e-01	1.308e+00	1.557e+00	3.557e+00
3	8.4090e+01	1.836e+00	2.626e+00	4.462e+00	3.056e+01	3.711e-01	1.000e+00	5.310e-01	1.430e+00	1.608e+00	4.033e+00
2	9.1700e+01	1.843e+00	2.883e+00	4.726e+00	3.222e+01	3.900e 01	1.000e+00	5.435e-01	1.564e+00	1.657e+00	4.562e+00
1	1.0000e+02	1.850e+00	3.163e+00	5.014e+00	3.392e+01	4.092e-01	1.000e+00	5.560e-01	1.710e+00	1.705e+00	5.151e+00

OEND OF DATPAC SUBROUTINE
OEND OF PROGRAM XGEN

AD-A165 589 ELECTRON INDUCED CONDUCTIVITY OF AL203 AS PERTAINING TO THERMIONIC INTEGRATED CIRCUITS(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA P J PETERSON DEC 85 2/2

UNCLASSIFIED F/G 9/5 NL

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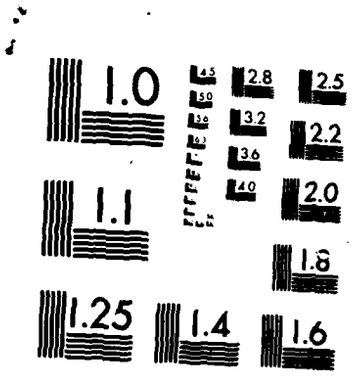

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1 ****************************************
  *                                      *
  *     PROGRAM ITS  - DECEMBER 16, 1984 *
  *             VERSION 1.0              *
  *                                      *
  ****************************************
  *          C Y L T R A N               *
  *          -------------               *
  ****************************************
ONUMBER OF MATERIALS
     1
O*********************************************************
 * GAMMA RAY CROSS SECTION DATA FOR MATERIAL NUMBER    1  *
 *********************************************************
OMPAIR  NTAB  MTAX
    25     2    47     3
OENERGIES (MEV)
 1000.000000  800.000000  600.000000  500.000000  400.000000  300.000000
  200.000000  150.000000  100.000000   80.000000   60.000000   50.000000
   40.000000   30.000000   20.000000   15.000000   10.000000    8.000000
    6.000000    5.000000    4.000000    3.000000    2.000000    1.500000
    1.000000    0.800000    0.600000    0.500000    0.400000    0.300000
    0.200000    0.150000    0.100000    0.080000    0.060000    0.050000
    0.040000    0.030000    0.020000    0.015000    0.010000    0.008000
    0.006000    0.004000    0.003000    0.002000    0.001560
    0.001560    0.001500    0.001000
OTOTAL ATTENUATION COEFFICIENTS (CM2/G)
    0.025959    0.025696    0.025309    0.025038    0.024655    0.024110
    0.023225    0.022530    0.021432    0.020683    0.020130    0.019897
    0.019643    0.019326    0.019284    0.019984    0.022013    0.023554
    0.026067    0.028045    0.030950    0.035557    0.043774    0.050809
    0.062365    0.069384    0.079029    0.085477    0.093701    0.104792
    0.121308    0.133987    0.156378    0.175386    0.219148    0.270559
    0.385203    0.710258    2.086195    4.815757   16.007493   30.982916
   72.117572  232.556618  521.692817 1549.204953 2881.499919
  839.180485  934.813698 2783.430664
ORATIO OF SCATTERING PLUS PAIR PRODUCTION TO TOTAL ATTENUATION COEFFICIENTS
    1.000000    1.000000    1.000000    1.000000    0.999999    0.999999
    0.999999    0.999998    0.999997    0.999997    0.999995    0.999994
    0.999993    0.999990    0.999985    0.999980    0.999971    0.999965
    0.999956    0.999949    0.999939    0.999922    0.999886    0.999843
    0.999731    0.999615    0.999342    0.999032    0.998380    0.996692
    0.990258    0.978220    0.930554    0.870801    0.734907    0.612536
    0.443408    0.248270    0.087430    0.038550    0.011811    0.006148
    0.002661    0.000832    0.000372    0.000128    0.000068
    0.000233    0.000209    0.000070
ORATIO OF SCATTERING TO SCATTERING PLUS PAIR PRODUCTION ATTENUATION COEFFICIENTS
    0.009152    0.011531    0.015553    0.018814    0.023779    0.032194
    0.049449    0.067071    0.103122    0.131197    0.174742    0.207697
    0.255283    0.330769    0.460659    0.556258    0.683981    0.750839
    0.829551    0.872441    0.915671    0.955921    0.987524    0.997280
    1.000000
OK SHELL IONIZATION DATA
OBINDING ENERGY (MEV), PHOTOEFFECT EFFICIENCY AND FLUORESCENT EFFICIENCY
    0.001560    0.709814    0.019542
OK X-RAY ENERGIES (MEV)
    0.001560    0.001560    0.001560    0.001560
OK X-RAY ACCUMULATED RELATIVE INTENSITIES
    1.000000    1.000000    1.000000    1.000000
OAUGER ELECTRON ENERGIES (MEV)
    0.001560    0.001560    0.001560
OAUGER ELECTRON ACCUMULATED RELATIVE INTENSITIES
    1.000000    1.000000    1.000000
1*********************************************************
```

```
 *    ELECTRON CROSS SECTION DATA FROM PROGRAM DATPAC     *
 ********************************************************
0NUMBER OF SETS ON DATAPAC TAPE =    1
0********************100.0 MEV CROSS SECTIONS SAPPHIRE                                        **********

0MATERIAL       DENSITY        DETOUR
        1  0.39650e+01  0.73100e+00
              Z                A                W
  0.80000e+01  0.15999e+02  0.47100e+00
  0.13000e+02  0.26981e+02  0.52900e+00
  NSET  ITRM  IZIP  ISGN  ISUB  INAL  ICYC  NCYC  NMAX       EMAX           EMIN           RMAX        LMAT
     1     5     0     1    40     1     1     8    64  1.0000000e+02  3.9062500e-01  3.3924240e+01      2
  DATAPREP DATA FOR DATAPAC SET    1    84    33    40   121  3.392424e+01

0 COLLISION / TOTAL DE/DX RATIOS FOR DATAPAC SET    1
0 CUMULATIVE BREMSSTRAHLUNG CROSS SECTIONS FOR DATAPAC SET    1
0 CUMULATIVE BREMSSTRAHLUNG ANGULAR DISTRIBUTIONS FOR DATAPAC SET    1
0 LANGAUSS - EQUIPROBABLE ENDPOINTS FOR INTERPOLATION
0 K X-RAY PRODUCTION FOR DATAPAC SET    1
0 PHOTOELECTRON ANGULAR DISTRIBUTIONS
0 PAIR ELECTRON ENERGY DIVISION DISTRIBUTION (LEAD)
1****************************
 *    BEGIN READING INPUT    *
 ****************************
 TITLE
 ...100.0 MEV TEST PROGRAM
 ************************SOURCE************************
 ELECTRONS
 ENERGY 100.0
 * DEFAULT SOURCE PHASE SPACE PARAMETERS
 * POSITION 0.0 0.0 0.0
 SOURCE-RADIUS 0.95250
0 WARNING, ILLEGAL COMMAND LINE - INFORMATION IGNORED
 -->SOURCE-RADIUS 0.95250
 * MONODIRECTIONAL Z-AXIS
 ********************OTHER OPTIONS********************
 HISTORIES 1000000
 BATCHES 10
 CUTOFFS 0.05 0.001
 ************************OUTPUT OPTIONS*****************
 ELECTRON-ESCAPE
 NBINE 10
 NBINT 10
 PHOTON-ESCAPE
 NBILE 10
 NBINT 10
 ELECTRON-FLUX 1 1
 NBINE 10
 PHOTON-FLUX 1 1
 NBINE 10
 ********************GEOMETRY************************
 GEOMETRY 1
 *ZL       ZR       RI       RO MAT   IZR   NZ.   NR  ECUT  PTCZ
 0.0 0.00297 0.0 0.95250 1 1 1 1 0.0 0.5
0 EOF ON UNIT  5 BEGIN PROCESSING - INPUT
1*************************************************** **********
 *    COMPARISON OF STORAGE REQUIREMENTS VS ALLOCATIONS    *
 ********************************************************
0NUMBER OF MATERIALS ON CROSS SECTION FILE                                  / INMT   =    1 /     5
 LENGTH OF ELECTRON CROSS SECTION ENERGY GRID                               / INMAX  =   64 /    64
 ELECTRON ENERGY GRID LENGTH FOR SAMPLING BREMS. PHOTON ENERGY              / INTOP  =   65 /    65
 PHOTON ENERGY GRID LENGTH FOR SAMPLING BREMS. PHOTON ENERGY                / IKTOP  =   49 /    49
 ELECTRON ANGLE GRID LENGTH FOR SAMPLING ELECTRON SCATTERING ANGLE          / INMAX  =   33 /    33
 PHOTON ANGLE GRID LENGTH FOR SAMPLING BREMS. PHOTON ANGLE                  / INPANG =   21 /    21
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 PHOTON ENERGY GRID LENGTH FOR SAMPLING BREMS. PHOTON ANGLE                    / INRANG  =   25  /   25
 ELECTRON ENERGY GRID LENGTH FOR SAMPLING BREMS. PHOTON ANGLE                  / INTANG  =    9  /    9
 PHOTON ENERGY GRID LENGTH FOR SAMPLING PHOTO-ELECTRON DIRECTION               / INEEL   =   13  /   17
 ELECTRON ANGLE GRID LENGTH FOR SAMPLING PHOTO-ELECTRON DIRECTION              / INPEL   =   21  /   21
 PHOTON ENERGY GRID LENGTH FOR SAMPLING PAIR ELECTRON ENERGY                   / INEPS   =    9  /   17
 ELECTRON ENERGY GRID LENGTH FOR SAMPLING PAIR ELECTON ENERGY                  / INPPS   =   21  /   21
 GAUSSIAN FUNCTION GRID FOR SAMPLING ELECTRON ENERGY LOSS STRAGGLING           / INGAS   =  100  /  100
 LANDAU FUNCTION GRID FOR SAMPLING ELECTRON ENERGY LOSS STRAGGLING             / INLAN   =  500  /  500
 MAXIMUM NUMBER OF TABLES OF PHOTON CROSS SECTIONS                             / INTAB   =    2  /   15
 MAXIMUM LENGTH OF PHOTON CROSS SECTION TABLE                                  / IMTAX   =   47  /   48
 NUMBER OF ELECTRON ESCAPE ENERGY BINS                                         / IJMAX   =   10  /   50
 NUMBER OF PHOTON ESCAPE ENERGY BINS                                           / IJPMAX  =   10  /   50
 NUMBER OF ELECTRON ESCAPE POLAR ANGLE BINS                                    / IKMAX   =   10  /   36
 NUMBER OF PHOTON ESCAPE POLAR ANGLE BINS                                      / IKPMAX  =   10  /   36
 LENGTH OF SOURCE SPECTRUM ENERGY GRID                                         / IJSPEC  =    0  /   51
 NUMBER OF PULSE HEIGHT ENERGY BINS                                            / IJSMAX  =    0  /   53
 NUMBER OF ELECTRON FLUX ENERGY BINS                                           / IJFMAX  =   10  /   50
 NUMBER OF PHOTON FLUX ENERGY BINS                                             / IJFMXP  =   10  /   50
 NUMBER OF ELECTRON FLUX ZONES                                                 / INLF    =    1  /   10
 NUMBER OF PHOTON FLUX ZONES                                                   / INLFP   =    1  /   10
 NUMBER OF PROBLEM ZONES                                                       / INZON   =    1  /  100
 SIZE OF DOUBLY DIFFERENTIAL BREMS DISTRIBUTION                                / NCHANG  = 4725  / 4725
 SIZE OF SINGLY DIFFERENTIAL BREMS DISTRIBUTION                                / NBDIS   = 3185  / 3185
 SIZE OF GOUDSMIT-SAUNDERSON ANGULAR DISTRIBUTION                              / NGG     = 2112  / 2112
 NO. OF ELECTRON ESCAPE AZIMUTHAL ANGLE BINS                                   / IKMAZ   =    1  /    1
 NO. OF PHOTON ESCAPE AZIMUTHAL ANGLE BINS                                     / IKPMAZ  =    1  /    1
O************* GLOBAL ELECTRON CUTOFF ENERGY BELOW ELECTRON ENERGY LIST.  CUTOFF ENERGY HAS BEEN CHANGED TO  0.408302e+00
!*********************************
 *   GEOMETRY DEPENDENT INPUT    *
 *********************************
ONUMBER OF INPUT ZONES =    1
O                          LEFT          RIGHT         INNER         OUTER        ELECTRON     PHOTON
                           PLANE         PLANE        RADIUS        RADIUS        CUTOFF      FORCING
  ZONE  MATERIAL           (CM)          (CM)          (CM)          (CM)          (MEV)       FRACTION
    1       1       0.00000e+00   2.97000e-03   0.00000e+00   9.52500e-01   4.083e-01   5.000e-01
!************************
 *  SOURCE INFORMATION  *
 ************************
OSOURCE ELECTRONS
OTHE MAXIMUM SOURCE ENERGY IS     100.00000 MEV
OTHE GLOBAL ELECTRON CUTOFF ENERGY IS       0.40830 MEV
OTHE PHOTON CUTOFF ENERGY IS       0.00100 MEV
OCOORDINATES OF THE POINT SOURCE OR OF THE CENTER OF THE BEAM (DISK) SOURCE ARE
     X =  0.00000e+00 CM          Y =  0.00000e+00 CM          Z =  0.00000e+00 CM
OTHE RADIUS OF THE BEAM (DISK) SOURCE IS =   0.0000e+00 CM
OREFERENCE DIRECTION FOR ANGULAR DISTRIBUTION IS DEFINED BY
      THETA =    0.0000 DEGREES          PHI =    0.0000 DEGREES
OMONODIRECTIONAL SOURCE IN REFERENCE DIRECTION
OTHE STANDARD ERROR ESTIMATES ARE BASED ON     10 BATCHES OF   100000 HISTORIES EACH
!********************
 *  OUTPUT OPTIONS  *
 ********************
OELECTRON-ESCAPE ENERGY CLASSIFICATIONS (MEV)
     90.00000     80.00000     70.00000     60.00000     50.00000     40.00000
     30.00000     20.00000     10.00000      0.40830
OELECTRON-ESCAPE POLAR ANGLE CLASSIFICATIONS (DEGREES)
     18.00000     36.00000     54.00000     72.00000     90.00000    108.00000
    126.00000    144.00000    162.00000    180.00000
OELECTRON-ESCAPE AZIMUTH ANGLE CLASSIFICATIONS (DEGREES)
    180.00000
OPHOTON-ESCAPE ENERGY CLASSIFICATIONS (MEV)
     90.00000     80.00000     70.00000     60.00000     50.00000     40.00000
     30.00000     20.00000     10.00000      0.00100
OPHOTON-ESCAPE POLAR ANGLE CLASSIFICATIONS (DEGREES)
```

```
    18.00000    36.00000    54.00000    72.00000    90.00000   108.00000
   126.00000   144.00000   162.00000   180.00000
OPHOTON-ESCAPE AZIMUTH ANGLE CLASSIFICATIONS (DEGREES)
   180.00000
OELECTRON-FLUX ENERGY CLASSIFICATIONS (MEV)
    90.00000    80.00000    70.00000    60.00000    50.00000    40.00000
    30.00000    20.00000    10.00000     0.40830
OPHOTON-FLUX ENERGY CLASSIFICATIONS (MEV)
    90.00000    80.00000    70.00000    60.00000    50.00000    40.00000
    30.00000    20.00000    10.00000     0.00100
1**********************
 *  PHYSICAL OPTIONS  *
 **********************
OELECTRON COLLISION AND RADIATION ENERGY LOSS STRAGGLING
OKNOCK-ON ELECTRON PRODUCTION
OND COUPLED INELASTIC SCATTERING DEFLECTIONS
OBREMSSTRAHLUNG AND CHARACTERISTIC X-RAY QUANTA FOLLOWED
OBREMSSTRAHLUNG INTRINSIC ANGLE OF EMISSION FROM TABULATED DISTRIBUTION
OPHOTON-PRODUCED ELECTRONS FOLLOWED
O       MATERIAL NO.  1
 ELECTRON RANGE AT MAXIMUM SOURCE ENERGY IS       0.33924e+02 (G/CM**2)
 K X-RAY QUANTA FOLLOWED
 ELECTRON IMPACT IONIZATION SAMPLED
OANNIHILATION QUANTA FOLLOWED
O THE VOLUME RATIO IS       0.1000000000000e+01
1*********************************************************************************
 *                                                                               *
 *  ...100.0 MEV TEST PROGRAM                                                    *
 *                                                                               *
 *********************************************************************************
OTHE PROBLEM IS  100  PERCENT COMPLETE.  TIME TO FINISH IS         0.000 SECONDS. AVERAGE TIME PER BATCH IS        13.142
OAVERAGE SOURCE ENERGY = 1.0000e+02  0 MEV
OTHE INITIAL RANDOM NUMBER OF THIS RUN IS 00000000000000000000
 THE INITIAL RANDOM NUMBER OF THE CURRENT BATCH IS 00005010720763211855
 THE  FINAL  RANDOM NUMBER OF THE CURRENT BATCH IS 00002747560732025178
O                                   HISTORIES                                    REJ      REJ        --- STEPS --
     PRIM       SEC     KNOCK       P-E      PAIR       COM     AUGER      BREM       RAD      XRAY      LAND      PEAL      PRIM       SI
  1000000      3847      2148          1       748       952         0      3480      3481      4775         1         0   1000000      39:
O                      ENERGY (MEV)       AVE ENERGY (MEV)      NUMBER/PRIMARY      NUMBER GENERATED
 FIRST KNOCK (ABOVE TCUT)      4.2222e-03          1.9702e+00          2.1430e-03             2143
 TOTAL KNOCK (ABOVE TCUT)      4.2235e-03          1.9681e+00          2.1460e-03             2146
 PHOTO-ELECTRON                2.1057e-06          4.8154e-04          4.6634e-03             2397
 PAIR                          3.1014e-06          1.7138e+01          1.8097e-07              758
 COMPTON                       1.1781e-06          1.0952e+00          1.0757e-06             2709
 AUGER                         3.7818e-04          1.5600e-03          2.4243e-01           240939
 FIRST BREMSSTRAHLUNG          3.8288e-02          1.1002e+01          3.4800e-03             3480
 TOTAL BREMSSTRAHLUNG          3.8288e-02          1.0999e+01          3.4810e-03             3481
 K X-RAY(P-IONIZATION)         1.1143e-07          1.5600e-03          7.1427e-05               36
 K X-RAY(E-IONIZATION)         7.3928e-06          1.5600e-03          4.7390e-03             4739
 ANNIHILATION QUANTA           2.1677e-10          5.1098e-01          4.2423e-10                2

1UNSCATTERED PRIMARY PHOTONS -- NUMBER AND ENERGY FRACTIONS
 0.00e+00 99 0.00e+00 99
 ***UNSCATTERED PRIMARY PHOTONS ARE EXCLUDED FROM ALL SUBSEQUENT PHOTON ESCAPE TALLIES***
ONUMBER ESCAPE FRACTIONS --- KNOCK-ON AND PHOTON GENERATED ELECTRONS, ANNIHILATION RADIATION, K-X-RAYS (MATERIAL NO.)
O                                   TRANSMISSION
        KNOCK          P-SEC          ANNIH     K-X-RAY(1)     K-X-RAY(2)     K-X-RAY(3)     K-X-RAY(4)     K-X-RAY(5)
   2.02e-03  2   4.80e-07  3   2.12e-10 99   4.06e-05  7
O                                   REFLECTION
        KNOCK          P-SEC          ANNIH     K-X-RAY(1)     K-X-RAY(2)     K-X-RAY(3)     K-X-RAY(4)     K-X-RAY(5)
   7.00e-06 30   7.28e-10 75   2.10e-10 99   3.60e-05 17
O                                   LATERAL ESCAPE
        KNOCK          P-SEC          ANNIH     K-X-RAY(1)     K-X-RAY(2)     K-X-RAY(3)     K-X-RAY(4)     K-X-RAY(5)
   0.00e+00 99   0.00e+00 99   0.00e+00 99   0.00e+00 99
```

```
0                                   NUMBER AND ENERGY ESCAPE FRACTIONS
0                                          TRANSMISSION
0                        ---------- ELECTRON ----------          ---------- PHOTON ----------
                           NUMBER      ENERGY      COUNTS        NUMBER      ENERGY      COUNTS

                        1.00e+00  0 1.00e+00  0     1003713  3.52e-03  1 3.83e-04  4        7151
0                                          REFLECTION
0                        ---------- ELECTRON ----------          ---------- PHOTON ----------
                           NUMBER      ENERGY      COUNTS        NUMBER      ENERGY      COUNTS

                        7.00e-08 30 3.33e-08 30          10  3.64e 05 17 1.21e-09  9        2905
0                                        LATERAL ESCAPE
0                        ---------- ELECTRON ----------          ---------- PHOTON ----------
                           NUMBER      ENERGY      COUNTS        NUMBER      ENERGY      COUNTS

                        0.00e+00 99 0.00e+00 99           0  5.25e-10 85 2.08e-12 88        7
1                                      ENERGY DEPOSITION
                                 (NORMALIZED TO ONE INCIDENT PARTICLE)
0                                                                          ENERGY DEPOSITION (MEV)
      ZONE       MATERIAL      MASS(GM)   VOLUME(CC)                          PRIM          KNOCK          G-SEC          TOTAL
        1            1       3.3564e-02     8.4652e-03                  1.9749e-02  0 -4.1869e-03  4  4.0052e 06  4  1.5559e 0.
0                                                          TOTAL         1.9749e-02  0 -4.1869e-03  4 -4.0052e-06  4  1.5559e-0.
0 THE ENERGY CONSERVATION FRACTION IS      0.1000043575875e+01  0
1                                      CHARGE DEPOSITION
                                 (NORMALIZED TO ONE INCIDENT PARTICLE)
0                                                                                ELECTRONS
      ZONE       MATERIAL      ZL          ZR          RI          RO              PRIM          KNOCK          G-SEC          TOTAL
        1            1    0.000e+00  2.970e-03  0.000e+00  9.525e-01   0.0000e+00 99-2.1430e-03  2-4.4098e-03  2-6.5528e-03  1

                                                                TOTAL   0.0000e+00 99-2.1430e-03  2-4.4098e-03  2-6.5528e-03  1

1FLUX CALCULATION - ELECTRONS LEFT AT FLUX CUTOFF ENERGY (NUMBER, NORMALIZED TO ONE INCIDENT PARTICLE)
      1
 1.21e-04  9
1                                    ELECTRON FLUX DISTRIBUTION
                          (TRACK-LENGTH/VOLUME-MEV, NORMALIZED TO ONE INCIDENT PARTICLE)
0E(MEV)  ZONE=     1

    90.0000   3.51e-02  0
    80.0000   9.23e-06  6
    70.0000   4.00e-06  9
    60.0000   2.00e-06 12
    50.0000   1.72e-06 18
    40.0000   1.45e-06 16
    30.0000   7.64e-07 16
    20.0000   5.22e-07 21
    10.0000   7.37e-07 15
     0.4083   5.98e-05  3
1                                    PHOTON FLUX DISTRIBUTION
                          (TRACK-LENGTH/VOLUME-MEV, NORMALIZED TO ONE INCIDENT PARTICLE)
0E(MEV)  ZONE=     1

    90.0000   4.58e-07 34
    80.0000   7.24e-07 21
    70.0000   7.51e-07 27
    60.0000   9.18e-07 25
    50.0000   9.30e-07 24
    40.0000   1.35e-06 17
    30.0000   1.99e-06 10
    20.0000   2.90e-06 13
    10.0000   6.26e-06  9
     0.0010   4.88e-05  3

     0
```

1 ENERGY SPECTRA OF TRANSMITTED ELECTRONS
(NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)

E (MEV)			
100.0000 -	90.0000	9.99e-02	0
90.0000 -	80.0000	3.46e-05	4
80.0000 -	70.0000	1.70e-05	8
70.0000 -	60.0000	1.03e-05	8
60.0000 -	50.0000	8.10e-06	10
50.0000 -	40.0000	7.20e-06	14
40.0000 -	30.0000	6.50e-06	13
30.0000 -	20.0000	6.40e-06	12
20.0000 -	10.0000	7.11e-06	14
10.0000 -	0.4083	2.08e-04	2

0 ENERGY SPECTRA OF REFLECTED ELECTRONS
(NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)

E (MEV)			
100.0000 -	90.0000	0.00e+00	99
90.0000 -	80.0000	0.00e+00	99
80.0000 -	70.0000	0.00e+00	99
70.0000 -	60.0000	0.00e+00	99
60.0000 -	50.0000	0.00e+00	99
50.0000 -	40.0000	0.00e+00	99
40.0000 -	30.0000	0.00e+00	99
30.0000 -	20.0000	0.00e+00	99
20.0000 -	10.0000	0.00e+00	99
10.0000 -	0.4083	7.30e-07	30

ENERGY SPECTRA OF LATERALLY ESCAPING ELECTRONS
(NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)

E (MEV)			
100.0000 -	90.0000	0.00e+00	99
90.0000 -	80.0000	0.00e+00	99
80.0000 -	70.0000	0.00e+00	99
70.0000 -	60.0000	0.00e+00	99
60.0000 -	50.0000	0.00e+00	99
50.0000 -	40.0000	0.00e+00	99
40.0000 -	30.0000	0.00e+00	99
30.0000 -	20.0000	0.00e+00	99
20.0000 -	10.0000	0.00e+00	99
10.0000 -	0.4083	0.00e+00	99

ANGULAR DISTRIBUTIONS OF TRANSMITTED AND REFLECTED ELECTRONS
(NUMBER/SR, NORMALIZED TO ONE INCIDENT PARTICLE)

0 PHI(DEG)= 0.000

THETA (DEG)	180.000		
0.0000 -	18.0000	3.25e+00	0
18.0000 -	36.0000	5.54e-04	7
36.0000 -	54.0000	6.99e-04	3
54.0000 -	72.0000	2.40e-04	5
72.0000 -	90.0000	2.37e-05	15
90.0000 -	108.0000	1.03e-06	67
108.0000 -	126.0000	1.12e-10	99
126.0000 -	144.0000	2.88e-06	55
144.0000 -	162.0000	0.00e+00	99
162.0000 -	180.0000	3.25e-06	99

ANGULAR DISTRIBUTIONS OF LATERALLY ESCAPING ELECTRONS
(NUMBER/SR, NORMALIZED TO ONE INCIDENT PARTICLE)

0 PHI(DEG)= 0.000

THETA (DEG)	180.000		
0.0000 -	18.0000	0.00e+00	99

18.0000	- 36.0000	0.00e+00	99
36.0000	- 54.0000	0.00e+00	99
54.0000	- 72.0000	0.00e+00	99
72.0000	- 90.0000	0.00e+00	99
90.0000	- 108.0000	0.00e+00	99
108.0000	- 126.0000	0.00e+00	99
126.0000	- 144.0000	0.00e+00	99
144.0000	- 162.0000	0.00e+00	99
162.0000	- 180.0000	0.00e+00	99

o ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF ELECTRONS TRANSMITTED AND REFLECTED
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

o E (MEV)		THETA= 0.000 18.000	18.000 36.000	36.000 54.000	54.000 72.000	72.000 90.000	90.000 108.000	108.000 126.000	126.000 144.000	144.000 162.000
100.0000	- 90.0000	3.25e-01	0 0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
90.0000	- 80.0000	1.13e-04	4 0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
80.0000	- 70.0000	5.53e-05	8 0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
70.0000	- 60.0000	3.35e-05	8 0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
60.0000	- 50.0000	2.63e-05	10 2.18e-11 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
50.0000	- 40.0000	2.34e-05	14 4.68e-11 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
40.0000	- 30.0000	2.11e-05	13 0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
30.0000	- 20.0000	2.08e-05	12 4.80e-11 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
20.0000	- 10.0000	2.28e-05	14 1.12e-07 99	9.80e-11 45	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
10.0000	- 0.4083	1.67e-05	13 5.76e-05 7	7.28e-05 3	2.51e-05 5	2.47e-06 15	1.07e-07 67	1.17e-11 99	3.00e-07 55	0.00e+0

o ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF ELECTRONS TRANSMITTED AND REFLECTED
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

o E (MEV)		THETA=162.000 180.000	
100.0000	- 90.0000	0.00e+00	99
90.0000	- 80.0000	0.00e+00	99
80.0000	- 70.0000	0.00e+00	99
70.0000	- 60.0000	0.00e+00	99
60.0000	- 50.0000	0.00e+00	99
50.0000	- 40.0000	0.00e+00	99
40.0000	- 30.0000	0.00e+00	99
30.0000	- 20.0000	0.00e+00	99
20.0000	- 10.0000	0.00e+00	99
10.0000	- 0.4083	3.39e-07	99

o ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF ELECTRONS LATERALLY ESCAPING
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

o E (MEV)		THETA= 0.000 18.000	18.000 36.000	36.000 54.000	54.000 72.000	72.000 90.000	90.000 108.000	108.000 126.000	126.000 144.000	144.000 162.000
100.0000	- 90.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
90.0000	- 80.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
80.0000	- 70.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
70.0000	- 60.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
60.0000	- 50.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
50.0000	- 40.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
40.0000	- 30.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
30.0000	- 20.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
20.0000	- 10.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0
10.0000	- 0.4083	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+0

o ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF ELECTRONS LATERALLY ESCAPING
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

0 THETA= 162.000
E (MEV) 180.000

100.0000 -	90.0000	0.00e+00	99
90.0000 -	80.0000	0.00e+00	99
80.0000 -	70.0000	0.00e+00	99
70.0000 -	60.0000	0.00e+00	99
60.0000 -	50.0000	0.00e+00	99
50.0000 -	40.0000	0.00e+00	99
40.0000 -	30.0000	0.00e+00	99
30.0000 -	20.0000	0.00e+00	99
20.0000 -	10.0000	0.00e+00	99
10.0000 -	0.4083	0.00e+00	99

1 ENERGY SPECTRA OF TRANSMITTED PHOTONS
(NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)

E (MEV)

100.0000 -	90.0000	2.70e-06	18
90.0000 -	80.0000	3.30e-06	18
80.0000 -	70.0000	4.60e-06	13
70.0000 -	60.0000	6.20e-06	14
60.0000 -	50.0000	8.60e-06	15
50.0000 -	40.0000	8.10e-06	10
40.0000 -	30.0000	1.03e-05	8
30.0000 -	20.0000	1.70e-05	8
20.0000 -	10.0000	3.45e-05	4
10.0000 -	0.0010	2.69e-04	2

0 ENERGY SPECTRA OF REFLECTED PHOTONS
(NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)

E (MEV)

100.0000 -	90.0000	0.00e+00	99
90.0000 -	80.0000	0.00e+00	99
80.0000 -	70.0000	0.00e+00	99
70.0000 -	60.0000	0.00e+00	99
60.0000 -	50.0000	0.00e+00	99
50.0000 -	40.0000	0.00e+00	99
40.0000 -	30.0000	0.00e+00	99
30.0000 -	20.0000	0.00e+00	99
20.0000 -	10.0000	0.00e+00	99
10.0000 -	0.0010	3.64e-06	17

ENERGY SPECTRA OF LATERALLY ESCAPING PHOTONS
(NUMBER/MEV, NORMALIZED TO ONE INCIDENT PARTICLE)

E (MEV)

100.0000 -	90.0000	0.00e+00	99
90.0000 -	80.0000	0.00e+00	99
80.0000 -	70.0000	0.00e+00	99
70.0000 -	60.0000	0.00e+00	99
60.0000 -	50.0000	0.00e+00	99
50.0000 -	40.0000	0.00e+00	99
40.0000 -	30.0000	0.00e+00	99
30.0000 -	20.0000	0.00e+00	99
20.0000 -	10.0000	0.00e+00	99
10.0000 -	0.0010	5.25e-11	85

ANGULAR DISTRIBUTIONS OF TRANSMITTED AND REFLECTED PHOTON INTENSITY
(MEV/SR, NORMALIZED TO ONE INCIDENT PARTICLE)

0 PHI(DEG)= 0.000
THETA (DEG) 180.000

0.0000 -	18.0000	1.24e-01	4
18.0000 -	36.0000	3.84e-07	48
36.0000 -	54.0000	8.31e-08	5
54.0000 -	72.0000	3.75e-08	9
72.0000 -	90.0000	1.97e-08	8
90.0000 -	108.0000	1.44e-08	16
108.0000 -	126.0000	1.90e-08	12
126.0000 -	144.0000	2.07e-08	19
144.0000 -	162.0000	2.80e-08	14
162.0000 -	180.0000	1.91e-08	39

ANGULAR DISTRIBUTIONS OF LATERALLY ESCAPING PHOTON INTENSITY
(MEV/SR, NORMALIZED TO ONE INCIDENT PARTICLE)

0 PHI(DEG)= 0.000
THETA (DEG) 180.000

0.0000 -	18.0000	0.00e+00	99
18.0000 -	36.0000	0.00e+00	99
36.0000 -	54.0000	0.00e+00	99
54.0000 -	72.0000	0.00e+00	99
72.0000 -	90.0000	7.16e-17	83
90.0000 -	108.0000	1.07e-10	88
108.0000 -	126.0000	0.00e+00	99
126.0000 -	144.0000	0.00e+00	99
144.0000 -	162.0000	0.00e+00	99
162.0000 -	180.0000	0.00e+00	99

0 ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF PHOTONS TRANSMITTED AND REFLECTED
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

0 THETA= 0.000 18.000 36.000 54.000 72.000 90.000 108.000 126.000 144.000
E (MEV) 18.000 36.000 54.000 72.000 90.000 108.000 126.000 144.000 162.000

100.0000	90.0000	8.78e-06	18	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99
90.0000 -	80.0000	1.07e-05	18	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99
80.0000 -	70.0000	1.50e-05	13	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99
70.0000 -	60.0000	2.02e-05	14	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99
60.0000 -	50.0000	2.15e-05	15	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99
50.0000 -	40.0000	2.63e-05	10	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99
40.0000 -	30.0000	3.35e-05	8	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99
30.0000 -	20.0000	5.53e-05	8	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99
20.0000 -	10.0000	1.12e-04	4	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99	0.00e+00	99
10.0000 -	0.0010	8.29e-04	2	9.71e-07	23	9.14e-07	19	7.84e-07	18	1.99e-07	34	1.61e-07	40	5.27e-07	27	7.94e-07	23	1.24e-0	
0 INTEGRAL (/SR)		1.13e-02	1	9.71e-06	23	9.14e-06	19	7.84e-06	18	1.99e-06	34	1.61e-06	40	5.27e-06	27	7.94e-06	23	1.24e-05	

0 ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF PHOTONS TRANSMITTED AND REFLECTED
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

0 THETA=162.000
E (MEV) 180.000

100.0000 -	90.0000	0.00e+00	99
90.0000 -	80.0000	0.00e+00	99
80.0000 -	70.0000	0.00e+00	99
70.0000 -	60.0000	0.00e+00	99
60.0000 -	50.0000	0.00e+00	99
50.0000 -	40.0000	0.00e+00	99
40.0000 -	30.0000	0.00e+00	99
30.0000 -	20.0000	0.00e+00	99
20.0000 -	10.0000	0.00e+00	99
10.0000 -	0.0010	6.40e-07	75
0 INTEGRAL (/SR)		6.40e-06	75

ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF PHOTONS LATERALLY ESCAPING
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

E (MEV)	THETA= 0.000 18.000	18.000 36.000	36.000 54.000	54.000 72.000	72.000 90.000	90.000 108.000	108.000 126.000	126.000 144.000	144.000 162.000
100.0000 - 90.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00
90.0000 - 80.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00
80.0000 - 70.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00
70.0000 - 60.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00
60.0000 - 50.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00
50.0000 - 40.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00
40.0000 - 30.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00
30.0000 - 20.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00
20.0000 - 10.0000	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00
10.0000 - 0.0010	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	2.46e-17 85	2.70e-11 85	0.00e+00 99	0.00e+00 99	0.00e+00
INTEGRAL (/SR)	0.00e+00 99	0.00e+00 99	0.00e+00 99	0.00e+00 99	2.46e-16 85	2.70e-10 85	0.00e+00 99	0.00e+00 99	0.00e+00

ENERGY SPECTRA AND ANGULAR DISTRIBUTIONS OF PHOTONS LATERALLY ESCAPING
AZIMUTHAL INTERVAL IS 0.00000 TO 180.00000 DEGREES
(NUMBER/(MEV*SR), NORMALIZED TO ONE PARTICLE)

E (MEV)	THETA=162.000 180.000
100.0000 - 90.0000	0.00e+00 99
90.0000 - 80.0000	0.00e+00 99
80.0000 - 70.0000	0.00e+00 99
70.0000 - 60.0000	0.00e+00 99
60.0000 - 50.0000	0.00e+00 99
50.0000 - 40.0000	0.00e+00 99
40.0000 - 30.0000	0.00e+00 99
30.0000 - 20.0000	0.00e+00 99
20.0000 - 10.0000	0.00e+00 99
10.0000 - 0.0010	0.00e+00 99
INTEGRAL (/SR)	0.00e+00 99

THE NUMBER OF DATA FOR WHICH STATISTICAL ESTIMATES HAVE BEEN PROVIDED IS 585

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